BC

Ministry of Environment

MOE WORKING REPORT

PORT ALICE SO_2 IMPACTS:
AIR QUALITY, SOIL, VEGETATION AND HEALTH

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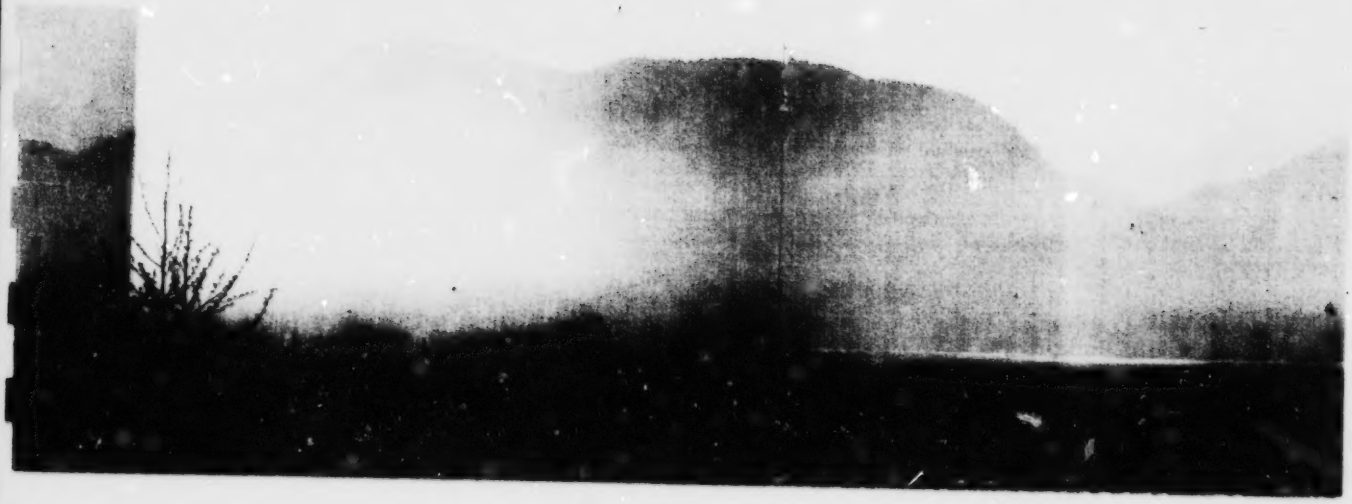
PLATE 1.1 Port Alice Sulphite Mill and Environs
(Photo R. Davis)



Executive Summary

In 1985 and 1986 the Ministry of Environment conducted a preliminary investigation to study and evaluate environmental impacts near the sulphite pulp mill in Port Alice, using available or collected preliminary information, and identify missing information required for a comprehensive assessment. As far as possible the emissions and their effects on the environment were tracked along the path through the atmosphere into vegetation and the soil. The available information on production, emissions, and air quality was reviewed and evaluated. Field samples of vegetation and soil were taken from 7 sites at various distances and in 3 cardinal directions from the mill. Additional samples were taken from a site near Port Hardy, where increased rain acidity had been observed, and from a site in the Tsitika drainage which was thought to reflect pristine environmental conditions.

A sulphite pulp mill was established at Port Alice in 1918. The initial daily production rate was 45 metric tons. By 1968 the mill had reached production capacity of 375 metric tons/day. In the 1970's and early 1980's a number of changes were made, and emission control systems incorporated. The production in 1983 was 420 metric tons/day. Present production rates (1987) are highest thus far at 468 tons/day.

Information on emissions from the mill was found to be incomplete. Estimates of SO_2 emissions since 1981 ranged from a lower limit between 4000 and 5000 kg/day (for an annual total of 0.8 million kg in 1981-82, a level somewhat similar to the emissions projected for the start-up in 1918), to an emission rate in 1986 of 21000 kg/day (annual total in excess of 6 million kg).

A distinct upward trend in emissions is evident. Although no emission rates are available for 1987 at this time, annual production has increased from the previous year.

Air quality information is very deficient. For the period 1981 to 1985 only unreliable, localized and incomplete data were available. More precise information was available from one locality for 1986 and 1987.

Data from a sulphation plate transect between Port Alice and Rumble Beach were available for 1981 and 1982. An indirect measure of air quality, these data enabled projection of annual atmospheric SO_2 concentrations of up to 318 $\mu g/m^3$ but an error of up to 25% may be inherent in this methodology. Also available were data for 1981 to 1985 from a Western Forest Products Ltd.-operated monitor. The actual ambient concentrations of SO_2 frequently exceeded the upper limit of the recording scale. However, the monitor was representative of very localized conditions in the Rumble Beach town site. Recently this monitor has been re-established at a more representative location. Due to the low upper detection limit and the frequency of "0" readings, means from this station may have (significantly) underestimated the local SO_2 exposure regime. Computed annual mean concentrations of SO_2 ranged from 34 $\mu g/m^3$ to 50 $\mu g/m^3$. The Ministry of Environment 1-Hour "B" Level objective of 900 $\mu g/m^3$ was exceeded on average 11 times per year, and was exceeded from 1 to 25 times during individual years.

A monitor operated by the Ministry of Environment, was located near the mill in an area which is not likely to represent an area of maximum exposure to SO_2. Air quality at

this monitor also repeatedly exceeded the recording scale and here also periods of "0" readings due to changing wind conditions or industrial shutdowns resulted in an underestimation of actual pollution doses experienced. Annual means of 1-hour averages increased significantly from 85 $\mu g/m^3$ in 1981 to over 206 $\mu g/^3$ in 1985. Monthly means of 1-Hour average ambient SO_2 concentrations for 1986 and 1987 ranged from 110 $\mu g/m^3$ to 350 $\mu g/m^3$. In this 2-year period Maximum 1-Hour average values ranged from 2000 $\mu g/m^3$ to 9400 $\mu g/m^3$. Monthly maximum 24-Hour average concentrations ranged from 325 $\mu g/m^3$ to 1900 $\mu g/m^3$. The 1-Hour Level "B" Objective (900 $\mu g/m3$) was exceeded from 56 times in 1981 to 395 times in 1986 for an annual average of 279 times. The Level "B" 24-Hour objective (260 $\mu g/m^3$) was exceeded 9 times in 1981 to 93 times in 1983 for an annual mean over the period 1981-1987 of 62 exceedances. The Level "C" 24-Hour Objective (800 $\mu g/m^3$) was exceeded 8 times in each of 1986 and 1987.

SO_2 concentrations observed at the ambient air monitoring stations cannot be applied to other areas. However, the distribution of maximum and mean concentrations in both space and time can be determined using an atmospheric dispersion model if representative emissions and meteorological data are available. Such data are unavailable for the Port Alice area.

The lack of meteorological data also makes it impossible to project the frequency with which pollutants are carried in the various directions.

The bioclimate of the area characteristically has a 3 month period (June-August) in which moisture deficiencies may occur. A distinct period of winter dormancy for conifers is

lacking. Drought stress may occur. No evidence was found that large-scale die-back occurred from drought in 1958, the driest year on record. Recently, 1985 also proved to be a very dry year, but no signs of large-scale die-back of forest trees in ecologically similar pristine areas are (as yet) evident.

Clear evidence of effects of sulphur deposition to the soils was found. Total sulphur increased with increasing proximity to the mill, while exchangable calcium and magnesium, base saturation, and pH decreased (ie. acidity increased).

Increased soil sulphur and decreasing soil pH affect decomposition of organic matter, reduce the availability of nitrogen and phosphorus, reduce the content of base cations, and increase the risk of mobilization of aluminum and toxic quantities of other trace elements.

Visible symptoms of acute and chronic injury to vegetation from contemporary SO_2 exposures were observed as far as Jeune Landing, a distance of 6 km NNW of the mill. Effects on plant growth may extend beyond this.

Near the mill, acute kill and die-back of western hemlock are observed, while western red cedar, coast Douglas-fir and amabilis fir regeneration are absent. A "lichen desert" of undetermined extent, occurs in the highly impacted area. Elevated levels of sulphur are found in plant tissues. Annual deposition of sulphate sulphur to the forest floor from needle fall is conservatively estimated as high as 125-250 kg/ha. For pristine areas this is estimated to be 10-20 kg/ha. Needle retention decreased (from approximately

5-7 years) to one or two years due to chronic build-up of sulphur. Frequent acute injury to plants, stress from SO_2 exposures and excess sulphate in tissues may cause greater disease susceptability.

The approximate injury threshold for coast Douglas-fir of 350 $\mu g/m^3$ 1-Hour mean was exceeded up to 1181 times in 1983 with only 1981, 1982 and 1984 being significantly lower in exceedances.

Historical damage is evident from the widespread occurrence of "veteran snags" of coast Douglas-fir, western red cedar, and probably amabilis fir. Over time changes to the soil may also have contributed to forest decline and reducted forest growth. Historical and present dispersal of insects and disease vectors does not account for the observed damage to the forest. Effects on the species composition of the vegetation communities were not determined in this preliminary study. Impacts on garden plants were observed in Rumble Beach. Significance of the impacts for forage and browse quality for the fauna of the area was not investigated.

The Canadian Maximum Acceptable Levels of Air Quality (1-Hour= 900 $\mu g/m^3$, 24-Hour= 300 $\mu g/m^3$, 1-Yr = 60 $\mu g/m^3$), which are intended to provide adequate protection for personal well-being and comfort, were exceeded at the monitor site in 1986 and 1987 respectively 394 and 346 times for 1-Hour Means and >76 times for 24-Hour Means.

At instantaneous concentrations greater than 2600 $\mu g/m^3$ all healthy members of the population can instantaneously detect (and experience discomfort from) the presence of SO_2. This

level was exceeded 78 times in 1986 and 41 times in 1987. The threshold for detection by sensitive people is 780 $\mu g/m^3$.

A 24-Hour Mean in excess of 400 $\mu g/m^3$ is associated with increased hospitalization for cardiac and respiratory illness and emergency room visits. Bronchitics experience worsening health at levels in excess of 500 $\mu g/m^3$. An appreciation of exceedances of these levels may be had from consideration of the number of exceedances for 1986 and 1987:

> 450 $\mu g/m^3$ 1-Hour Mean was exceeded respectively 876 and 922 times; 350 $\mu g/m^3$ 1-Hour Mean was exceeded respectively 1114 and 1159 times; and 360 $\mu g/m^3$ 24-Hour Mean was exceeded respectively 8 and 3 times. No information on 24-Hour mean SO_2 levels in Rumble Beach is available.

Annual Means in excess of 60 $\mu g/m^3$ present a risk of acute respiratory illness for small children and of chest illness for lifetime residents. No data is available to evaluate the risk from such chronic exposures. However Monthly Means, which give some indication of prolonged exposures, are greater than the annual threshold values. A Monthly Mean of 150 $\mu g/m^3$ is exceeded more than 7 times in 1986 and 1987 each near the Mill. For Rumble Beach Annual Means of between 101 $\mu g/m^3$ and 186 $\mu g/m^3$ were projected for 1981-82. These Means were likely greater in 1986 and 1987.

The presence of suspended particulates may aggravate the effects of SO_2 exposures and lower tolerance thresholds.

A risk to health for the general population is indicated. Sensitive groups of the population are more seriously in danger of illness.

The exceedances apply to the specific monitor location. The number of exceedances throughout the area as a whole, are projected to be substantially greater.

Epidemiological data to determine effects on public health in comparison to that of a "control group", and to determine relationships between health and variations in exposure within the community, were beyond the scope of this preliminary investigation.

Effects on water quality and wildlife were also beyond the scope of this preliminary investigation.

It was concluded that significant impacts on the environment have occurred and public health may be at risk. Impacts are likely to increase with increasing emissions from the mill. A comprehensive assessment of the effects is warranted.

In addition to appropriate determinations of impacts on water quality, and the regional fauna, the following components for assessments of impact on air quality, soil, vegetation, and health are recommended:

Recommendations Towards a Comprehensive Impact Assessment:

EMISSIONS

1: CONDUCT A COMPREHENSIVE EMISSION INVENTORY

2: IMPLEMENT AND EVALUATE CONTINUOUS MONITORING OF ACID PLANT AND RECOVERY FURNACE/BLOW GAS ADSORPTION STACKS FOR SO_2 EMISSIONS

AIR QUALITY

1: ESTABLISH AND OPERATE A METEOROLOGICAL STATION

2: ESTABLISH, UPGRADE, AND MAINTAIN SO_2 AND PARTICULATE MONITORING STATIONS

3: ESTABLISH AND OPERATE ACID RAIN STATIONS

SOILS

1: MAP LAND BASE AT APPROPRIATE SCALE AND ASSESS SENSITIVITY TO ACID DEPOSITION

2: MONITOR SOIL PROCESSES AT BENCHMARK SITES

3: CONDUCT LIMING RESPONSE EXPERIMENTS

4: MODEL SOIL IMPACTS FROM ACID DEPOSITION

VEGETATION

1: ON REPRESENTATIVE SITES DETERMINE AND QUANTIFY THE IMPACTS FROM AIR QUALITY ON:
FOREST GROWTH AND HEALTH, TREE SPECIES DISTRIBUTION, VEGETATION COMMUNITY COMPOSITION, DISTRIBUTION OF BRYOPHYTES AND LICHENS, AND TISSUE SULPHUR CONTENT FOR EACH OF THE SIGNIFICANT ECOSYSTEM TYPES OF THE IMPACTED AREA

2: USING PROJECTED AIR POLLUTION PATTERNS AND THE SOILS LAND-BASE MAP IN CONJUNCTION WITH THE RESULTS OF "1" ASSESS AND MAP THE ENVIRONMENTAL IMPACT ON THE AREA

3: MONITOR SULPHUR MINERAL CYCLE AND FOREST GROWTH, AND SPECIES DIVERSITY ON SELECTED BENCHMARK SITES

4: PERFORM TREE RING ANALYSIS TO ESTABLISH PATTERNS OF FOREST BIE-BACK

HEALTH

1: CONTINUED COMPILATION OF AIR QUALITY DATA FOR INSTANTANEOUS, PERIODIC, AND CHRONIC HEALTH RISKS

2: DETERMINE HEALTH RISK FOR VARIOUS GROUPS OF THE POPULATION

3: CONDUCT EPIDEMIOLOGICAL STUDIES FOR APPROPRIATE GROUPS OF THE POPULATION

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CHAPTER ONE
INTRODUCTION

1.1 Study Area Characteristics

Port Alice has been home to a sulphite pulpmill since 1918[1]. It is located on the eastern shore of Neroutsos Inlet in the northern part of Vancouver Island at a longitude of 127° 27' and a latitude of 50° 15' (Figure 1.1). The community of Rumble Beach, approximately 3.5 km north of the mill site, houses the employees of the mill. Most residents of this community are dependent, directly or indirectly, on the mill for their livelihood.

The area is located in the Nootka Section of the Outer Coast Vegetation Region and most of the area is within the Coastal western hemlock pacific silver fir zone: western red cedar subzone (CwH-aF(a))[2]. The Biogeoclimatic classification places this area in the Coastal western hemlock zone: wet subzone (CwHb) of the Pacific Coastal Mesothermal Forest BGC Region [3,8,3,4]. Forest Regions of Canada[5] identifies the area as a part of Southern Pacific Coast Section (C.2) of the Coast Forest Region.

The climate of the study area is characterized by high precipitation, cool temperatures and mild winters (Table 1.1).

Port Alice is located near the northern extent of the Vancouver mountains[6]. The topography is relatively subdued, ranging from sea level to a height of land less than 1280 m. The land typically slopes steeply with eastern or western

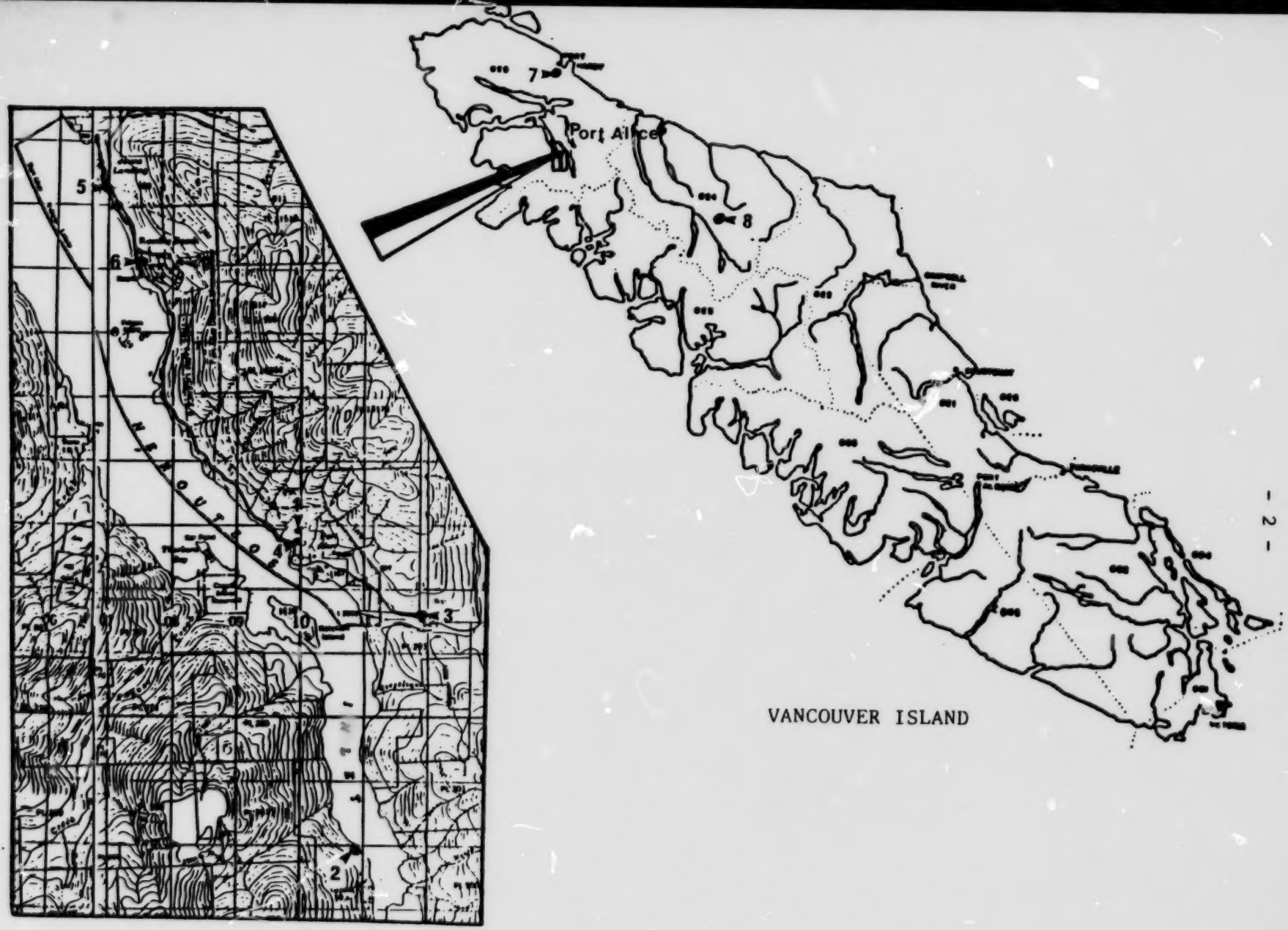


Figure 1.1 Location of Study Area and Sampling Sites

TABLE 1.1
CLIMATE CHARACTERISTICS

Port Alice (Altitude 15m)

CHARACTERISTIC	PARAMETER		COMMENTS
TEMPERATURE:	Mean Annual	12.9°C	
(Maximums)	Mean January	5.4°C	coolest
	Mean July	20.5°C	warmest
PRECIPITATION:			
Snow	Mean Annual	58.4 cm	
	Period	Nov-Mar	
	January Total	28 cm	highest snowfall
Rain	Mean Annual	318.1 cm	
	Mean December	52.2 cm	wettest
	Mean July	6.4 cm	driest
	Period May-Aug	33.6 cm	dry
FREEZING:			
F.F.P.		222 days	
	Mar 27-Dec 23	270 days	longest
	Apr 22-Sept 26	156 days	shortest
HEAT UNITS:			
(above 5°C)	Mean Annual	1763 DD	
	August	342 DD	warmest
	Period May-Oct	1529 DD	

From: Canadian Climate Normals 1951-1980, Volumes 3,4,5,6,8, and Temperature and Precipitation, British Columbia. Environment Canada, 1982.

exposures, as the lakes and sea filled valleys have a north-south orientation. Rolling upland plateaus occur typically at approximately 1100 m above sea level. Bedrock is of sedimentary and volcanic origin with limestones and sandstones locally abundant.[61]

With the exception of marine deposits along the immediate shoreline of Neroutsos Inlet, colluvial (gravity fall) materials and some morainal materials (glacial till) dominate in the Port Alice area. A variety of materials occur in the immediate area of Port Hardy, but the area sampled has morainal materials (glacial till) underlain by colluvium. Soils in the Port Alice area are classed as Ferro-Humic Podzols, or soils typical of those developed in a high rainfall, forested area. Their dominant features are a forest litter surface horizon and an underlying red, acidic, iron and aluminum rich subsurface horizon. Similar soils occur in the Port Hardy and Tsitika sampling areas. The soils are well drained on the mid and upper slopes, with seepage surfacing near the banks and at the foot of the lower slopes. The associated vegetation reflects these environmental conditions. Acid tolerant species, such as western hemlock and heather family species (salal, blueberries) dominate. Nutrient enriched seepage sites also support western red cedar and ferns, including swordfern and deerfern. Red alder often dominates successional stages on richer sites, while western hemlock reinvades well-drained deep soils. Shallower soils, particularly on a limestone substrate may feature western white pine, and coast Douglas-fir. The humid environment is expected to be favourable for epiphytic lichens in those parts of the canopy receiving sufficient light[8]. Acid requiring decay organisms,

fungi, could flourish under these conditions if sufficient nutrients are available.

1.2 Objectives

Since 1918 emissions of SO_2 over the years may have adversely affected the environment of the area. This may account for lost resource values and opportunities.

A preliminary assessment was undertaken to study and evaluate environmental impacts, using available or collected preliminary information, and identify missing information required for a comprehensive assessment.

This preliminary assessment aimed:

1) to determine if soil and vegetation were affected. Acidification and associated effects, sulphur loading, and mineralization are of concern for soil, while for vegetation effects on diversity, health, and growth are investigated.

2) to investigate the sensitivity and susceptibility of the environment to damage from adverse air emissions, taking into account climate, soils, and other environmental conditions determining the diversity, health, and growth of the living system.

3) to describe the ambient air quality and temporal changes in air quality as monitored in the Port Alice area and to assess the representativeness of

monitored air quality data as an indicator of the ambient air quality of that area.

4) to determine if the air quality may represent a health risk for the residents and workers of the Port Alice and Rumble Beach area.

1.3 Background

The preliminary investigation for the occurrence of impacts is based on an ecosystem approach. The environment is broadly partitioned into atmosphere, vegetation, and soils. The pathway of the contaminants is tracked from the mill, through the atmosphere, to the vegetation and soil. This is reflected in report sections: emissions, air quality, vegetation, and soil. In each of these sections it is attempted to estimate the input of pollutants and to identify effects that the contaminant produced on the functioning and condition of the components; including public health. Information on direct deposition of sulphur to the soil is not available, so that no quantitative estimate is possible.

Omitted from this assessment are:

i) consideration of impacts on the aquatic environment.

ii) effects on the fauna, directly from adverse air quality conditions, and indirectly from the effects of sulphur on habitat and food.

iii) epidemiological effects on public health of workers and residents of the area.

To some degree, expectations of impacts on water quality, wildlife forage and habitat, and human health may be inferred from the information on soil, vegetation and air quality.

The ecosystem approach also served as a framework for the recommendations for a comprehensive evaluation of impacts.

1.3.1 Emissions

In the proximity of Port Alice SO_2 may originate from global air circulation, local domestic sources and the sulphite pulp mill. Background levels originating with global air circulation (5-27 $\mu g/m^3$) are minimal[76] relative to the local atmospheric levels. Local domestic sources are insignificant as Rumble Beach is a small residential community of less than 1000 dwellings. The sulphite pulp mill has permits for emissions to the air from several sources (Figure 3.1.1). Emissions include particulates, sulphur dioxide, chlorine and chlorine dioxide.

1.3.2 Air Quality

Air quality is quantified using monitoring instrumentation and it is commonly expressed as a mass per unit volume concentration for individual pollutants.

The air quality of any particular area represents the net effect of natural background levels of pollutants, pollutants advected from surrounding areas, and pollutants discharged from anthropogenic sources within the area.

The impact of atmospheric pollutant emissions on local air quality is dependent on the characteristics of the atmosphere

both at the time of release and during the period of pollutant transport. The degree of impact is dependent on the wind speed, wind direction, atmospheric stability, atmospheric mixing height, and ambient temperature so that, even with constant release rates, impacts on regional air quality are highly variable.

The air quality at specific geographic locations is also greatly influenced by local terrain and topography. Site elevation and orientation relative to pollutant sources as well as local surface cover and air circulation, affect air quality on a local scale.

Pollutants released into the atmosphere from industrial stacks emerge as discreet puffs or prolonged plumes. In either case, the pollutant 'cloud' begins to expand upon release as ambient air is entrained and mixed into the pollutant mass. The 'cloud' spreads both horizontally and vertically at rates which are determined by atmospheric conditions. The entrainment of ambient air occurs from the outside of the 'cloud' towards the centre and, as a consequence, a three-dimensional concentration gradient is created through the pollutant mass. The greatest concentrations occur at the centre of the 'cloud' and the smallest concentrations occur along the interface with the ambient air.

Recognizing the existence of a concentration gradient within a pollutant 'cloud' is especially important when evaluating local air quality. This is also true when determining the optimum siting of ambient air quality monitors and when assessing the air quality data subsequently collected.

Air quality of the Port Alice area is affected primarily by emissions from the local sulphite mill and the effects of local climate and topography. Diurnal air flows, temperature inversions and the general westerly air flows are directed and modified by the local topography. Under these conditions air flows are complex and their effects on transport and "dilution" of atmospheric emissions are not readily apparent. Air quality information for the area was absent until 1981, when a monitoring program was initiated. However, many uncertainties exist regarding the spatial and temporal character of air quality.

1.3.3 Soils

A full discussion of the many aspects of sulphur in soils is beyond the scope of this report. The number of forms of sulphur believed present in soils, the numerous oxidation states, the immobilization and adsorption processes which can take place, and the inorganic and biologically mediated oxidation and reduction mechanisms, are numerous and complex. Burns[62], though somewhat dated, provides an appropriate summary of basic soil sulphur chemistry.

In humid-region soils, particularly those not receiving sulphur from atmospheric deposition, most sulphur is associated with organic compounds. This soil organic fraction can serve either as a source of nutrient sulphur for plants or as a means of storage for sulphur, but is normally considered to be a source. Oxidation, or the release of the organically bound sulphur, can be either through inorganic chemical (non-biological or auto-chemical) processes or biological (microbial) processes. The latter is relatively

slow, but is usually of greater importance and is continual unless stopped by some condition adverse to microorganisms such as freezing, flooding, or severe drought.

Sulphur, to some extent, exists in inorganic forms in all soils. In fact, end products of oxidation are inorganic sulphate-sulphur. However, in soils exposed to elevated levels of gaseous sulphur compounds (e.g., sulphur dioxide or hydrogen sulphide), or receiving sulphur in wet or dry deposition from the atmosphere, inorganic contents may be significantly higher than is considered normal for field soils. The dominant inorganic form of sulphur in most well drained soils is sulphate, though minor amounts of lower oxidation state compounds may be present. Sulphate in the soil solution is most commonly associated with Ca, Mg, Na and K cations. Sulphate may also be adsorbed in soils, held by ligand exchange mechanisms with Fe and Al oxides and hydrous oxides. Thus acidic soils (pH <6.6) with high contents of these components will have the largest relative amounts adsorbed sulphur. Neutral or calcareous soils are expected to have negligible amounts of this form of sulphur.

Total sulphur of field soils has been reported as ranging from 0 to 0.06% (0 to 600 ppm) and higher. Commonly, however, soil sulphur ranges between 0.01% and 0.05% (100 to 500 ppm). It is generally believed that sulphate sulphur is less than 25% of total sulphur and that for many soils it is considerably less. It is possible, however, that sulphate associated with organic matter may not have been measured in the past due to inappropriate extraction methods, and therefore sulphate amount in soils are actually higher than reported at that time.

Soils can absorb gaseous sulphur dioxide directly. Abeles et al.[63] demonstrated, in laboratory experiments, a large capacity of soils to absorb sulphur dioxide. Cox[64] located soils in containers under canopies downwind from sulphur dioxide emitting smelters (reported in Nyborg et al.,[65]). They were, therefore, protected from deposition of sulphur in precipitation. He reported pH reductions of 0.2 to 0.4 units at distances of 15 to 25 km from source in 19 weeks of exposure. Ghiorse and Alexander[66] found that sulphur dioxide was rapidly removed from the gaseous phase by both sterile and non-sterile soils, indicating microorganisms are not directly involved in removal from the air. Sulphate was formed in both sterile and non-sterile soils but about 25% was not recoverable as inorganic sulphur until organic matter was destroyed. It was, therefore, postulated that soil organic matter provides additional sites for initial sorption or provides carbonyl groups with which the sorption products can form sulphite-addition compounds. It was also suggested that microorganisms may passively participate in the process, providing additional organic materials for reaction with sulphur dioxide. Nyborg et al. reported on both sulphate and total sulphur contents of bare soils placed under rain shelters at varying distances from sulphur dioxide sources. Contents of both increased significantly within the four month period of exposure. As well, a significant positive correlation between total sulphation (a measure of gaseous sulphur loading) and soil sulphate sulphur was demonstrated.

Sulphur dioxide can be hydrolyzed and oxidized in the atmosphere or in the soil solution, and therefore, may be deposited as acidic precipitation or produce hydrogen ions by reaction with soil water. In either case, reductions in soil

pH would be the result. Ghiorse and Alexander[66] demonstrated rapid initial pH reductions in soils exposed to sulphur dioxide. Yee et al.[67] showed the pH reduction as well as sulphate content to be related to soil sulphur dioxide concentration as well as to soil water content. Nyborg et al.[65] also showed decreases in pH in soils under rain canopies, exposed to ambient air for four months in the vicinity of sulphur dioxide sources.

Numerous soil property changes can occur as a result of sulphur dioxide absorption by, or acidic deposition on soil. Some of these changes include: pH reductions; leaching of base cations; solubilization of aluminum, iron, trace elements and heavy metals; reduced availability to plants of phosphorus in soil; reduction in organic matter decomposition and nitrogen mineralization; and increases in sulphur content. A large body of literature on these changes has developed as a result of studies on the impacts of acid rain. Several review articles which might be cited include: Reuss and Johnson[68]; Bengay and Riordan[69]; Province of Ontario[70]; and Linzon[71].

The extent to which these changes occur in soils will depend on both the exposure to sulphur dioxide and the deposition of acidic inputs, as well as on soil factors. Important soil factors include: initial pH; texture and organic matter content which can affect cation exchange capacity; exchangeable base content; carbonate content; and, contents of other components such as oxides and hydrous oxides. Many of these factors in combination affect soil buffering capacity. This is a measure of the capacity of soil to resist changes in acidity.

Sulphur is an essential element for plant growth. Sulphur deficiencies in soils are known to exist in many areas and may be limiting to crop production and natural vegetation growth. Sulphur is required by plants in about the same amounts as phosphorus, an element classed as a major plant nutrient. Most sulphur adsorbed by the roots is translocated unchanged to the shoots and incorporated, primarily into sulphur-containing amino acids which are incorporated into proteins. Other essential sulphur-containing compounds are the respiratory compound coenzyme A and the vitamins thiamine and biotin. The functions of a number of other sulphur-containing compounds in plants are unknown.

Sulphur is adsorbed by plant roots from soils primarily as the divalent sulphate ion. Thus, elemental sulphur or organic matter additions (e.g., plant residues and other soil organic matter) must first undergo oxidation before they become available to plants.

In addition to direct nutritional effects of sulphur on plants, additions of sulphur to soils can affect vegetation as a result of the soil property changes already indicated. (These are additional to the direct effects of sulphur dioxide on vegetation.) Acidification (reduction of soil pH), loss of exchangeable bases, and solubilization of metals, particularly aluminum, are believed to be among the most significant soil changes affecting vegetation.

Sulphur accumulations and associated changes in British Columbia soils as a result of air emissions and deposition have been evaluated in several locations in the past. These

have been in areas of concern related to mining, milling, or smelting of sulphide ores rather than in areas of sulphur dioxide emissions from pulp mills.

The effects of sulphur dioxide emissions from the Cominco Ltd. Smelter in Trail, B.C. were studied and reported on in the 1930s under the sponsorship of the International Joint Commissions. Major sulphur dioxide control works were initiated as a result of study findings. Katz[15,72] reported that as a result of sampling over 600 soils in the area of Trail, B.C. and analyzing for hydrogen ion concentration, exchangeable hydrogen, base-exchange capacity, and sulphate content, a pattern of low pH and base saturation, and abnormally high sulphate contents were found in soils within 4 to 8 miles north and south of the smelter.

As reported in Water Investigation Branch[73], Wiens sampled soils in the area of the Sullivan Pb/Zn mine, concentrator, and fertilizer plant in Kimberley, B.C. Soils were analyzed for the elements Pb, Zn, As, F, and sulphur. Sulphur in thin surface organic horizons ranged from 1350 to 1600 ppm, and in subsurface horizons from 90 to 450 ppm. In mixed samples, the values ranged from 130 to 1400 ppm.

In the same area (Kimberley), "background" soil sample sulphur values reported by Lavkulich et al.[88] were in the range 60 to 130 ppm.

Samples collected in the Trail area[73] showed sulphur contents for surface soils to range from 230 to 1760 ppm and for subsurface soils to range from 130 to 810 ppm.

Samples taken in the area of the Afton Mines Ltd. copper smelter in Kamloops, B.C.[89] indicate a range of total sulphur of <30 ppm to 940 ppm for soil sampled in the period 1976 to 1978.

1.3.4 Vegetation

Effects of sulphur dioxide on plants are well documented[9, 10, 11, 12, 15]. Symptoms are described in Malhotra and Blauel[13]. Sulphur dioxide is taken up through the stomates. Where the gas impinges on the wet surfaces of the cells inside the leaves bisulphite is formed. This compound is highly toxic and affects the functioning of the cell walls and membranes. The bisulphite is subsequently oxidized into relatively harmless sulphate, which is disposed of into the vacuoles of the tissue cells, where it may accumulate. When in small doses, this continuous process may prevent injury from SO_2. However, higher concentrations of SO_2 in the ambient air will result in injury to the plant cells from bisulphite toxicity.

SO_2 may impact on vegetation in a variety of ways depending on:

a) species - plants vary in tolerance of SO_2 among species, ecotypes, varieties and cultivars.

b) physiological activity - the activity and growth rate of the plant is directly related to the rate of gas uptake. It varies with climate and weather conditions, soil moisture and fertility and atmospheric quality.

c) ecosystem - which relates to the above physical conditions (climate, soils, as well as the associated biota).

d) health of the plants - which includes injury and disease and senescence.

The impacts and effects may manifest themselves in a variety of ways depending on the characteristics of the SO_2 exposure.

1) acute impacts are caused by relatively high concentrations. Injury occurs over a short period of time and may be evident as:

   i) chlorosis
   ii) necrosis
   iii) defoliation
   iv) death

2) chronic impacts may result from lower or higher concentrations acting over a long period of time. Chronic injury may be superimposed on acute injury. It may be evident from:

   i) reduced growth - injury may or not be evident, but the growth potential of the plant was inhibited

   ii) increased incidence of disease, possibly following injury or from weakening defence mechanisms

iii) unusual accumulations of chemicals in the tissues

iv) survival of species depending on: threshold tolerance levels (low for lichens and mosses); longevity of photosynthesizing tissue (i.e. short for deciduous and longer for evergreen); and rate of accumulation of chemicals in tissues.

CHAPTER TWO
METHODS

In keeping with the preliminary nature of the objectives, the sampling and observations did not occur in a rigidly designed pattern that would readily allow statistical testing of hypotheses. The methods and analyses served primarily to detect trends and to determine the (qualitative) nature of possible impacts.

2.1 Siting and Site Selection

2.1.1 Prior to the Present Study

In 1980, ten sulphation plate sites were established by Western Forest Products. These were operated until the end of 1982 (Figure 1.1). A transect consisting of seven sites was located between Rumble Beach (5.8 km from Port Alice pulpmill) and Port Alice (1.2 km from the pulpmill) at low elevations along the main road. This transect was established to identify the gradient of sulphation rates which existed between the Port Alice pulpmill and the community of Rumble Beach. Sites were also established 1.0, 0.9, and 1.8 km southeast of the pulpmill; the latter two being located at slightly higher elevations. No altitudinal transect was established.

From 1980 to 1987, an SO_2 monitor was operated in Rumble Beach (Figure 1.1) by Western Forest Products Ltd. to determine the impact of SO_2 from the Port Alice pulpmill on the ambient air quality of this residential area. Although Ministry siting requirements were generally met, interference

from surrounding housing and terrain may have influenced the exposure of the SO_2 analyzer to pollutant impacts. Intermittent residential sources of SO_2 which were located within 10 metres of the analyzer, occasionally may have influenced monitored concentrations.

In early 1988 the Rumble Beach SO_2 monitor was moved to a site considered to be more representative of the air quality of the area. As of July 1988, this site is in operation.

An SO_2 monitor was established in Port Alice in February 1981 by the B.C. Ministry of Environment, Waste Management Branch (Figure 1.1). Located at an elevation of 60 metres and approximately 600 metres northwest of the Western Forest Products pulpmill, it was located to monitor SO_2 concentrations near the pulpmill when winds are blowing towards Rumble Beach. The monitor also served as counterpoint to the Rumble Beach SO_2 monitor operated by Western Forest Products.

The monitor is situated in a mobile trailer on a small, gently sloping, terraced site near the base of a 900 metre mountain. The analyzer location was selected to permit convenient vehicle access and access to a source of AC power. The site is relatively open to the south-southwest quadrant but was otherwise surrounded by alder stands of up to 10 metres in height.

A Department of Transport (now Atmospheric Environment Service) climatological station was established in 1924 very near to the Port Alice pulpmill complex. Between 1924 and 1955 this station monitored only daily precipitation. From 1955 to the present, daily temperatures were also monitored.

From late 1975 to 1978 an Atmospheric Environment Service climatological station was operated at a residential location in Rumble Beach. This station monitored daily precipitation and temperature.

In the early 1980's, meteorological instrumentation was established by Western Forest Products at a roof-top location of the Port Alice pulpmill. However data quality is poor and little usable data were obtained from this installation.

2.1.2 Sites Selected for this Study

As no information was available regarding atmospheric dispersal mechanisms, soil and vegetation sampling sites were positioned in 3 major directions from the mill. These sites are not selected in consideration of wind patterns and local meteorology; and, therefore, may not be representative of air quality gradients. It would only be fortuitous if the selected sampling sites include the area of maximum SO_2 impingement. The number of selected sites also does not represent the full spectrum of ecosystems of the area. It is, therefore, not feasible to construct a quantitative assessment of impacts on the basis of this preliminary information.

The sites were projected to be representative of some ecosystems of the area and are selected to be reasonably consistent in terms of soil depth and soil materials. All sites were located within a single ecological belt, thus ensuring consistent climatic characteristics. Some climatic differences resulted from topographic positioning in the local terrain. However, in this ocean-moderated environment

such differences appeared acceptable for general comparison purposes. Site moisture regimes varied from well-drained and mesic to imperfectly drained and sub-hygric. These environmental differences accounted for some of the differences in the growth capability of the trees and differences in the species composition of overstory and understory vegetation. However, sufficient characteristics were in common between the various sites (see Figure 1.1 and Table 3.5.1) to ensure that useful qualitative comparisons could be made.

The selected soil-vegetation sampling sites represent:

- a control site and several affected sites.
- sites on a transect in line with the predominant wind direction(s) in the area of the pulp mill.
- sites with varying exposure to air emissions from the mill.

Sites were selected in three general areas, namely:

- Area A: Port Alice (affected to varying degrees).
- Area B: Port Hardy (possibly affected as indicated by precipitation chemistry results).
- Area C: Tsitika or Nimkish Valley S. (believed to be unaffected, and, therefore, a control).

Site 4 was chosen at the air quality monitoring station just north of the mill in the downwind position for the prevailing winds. Site 1 was located above Site 4 to determine if a rising plume would impact higher on the slope. Both sites were located within the area of severe visible impact on the forests. Site 3 was located east of the mill near a relatively low pass in the topography. Westerly winds would

carry emissions from the mill in this direction. Little visible impact was evident south of the mill. Site 2 was located 4 km south of the mill in a direct line of sight across the inlet. As most of the visible impact occurred in a northerly direction, a transect of sites was located to determine how far measurable symptoms occurred. Site 6 was located in the townsite of Rumble Beach along the shore of Neroutsos Inlet, approximately 5.5 km NNW of the mill. Site 5 was located near Jeune Landing approximately 7 km NNW of the mill. As a correlation between pH of rainwater and production at the mill had been hypothesized[14], sample Site 7 was located near Port Hardy approximately 24 km north of the Port Alice pulpmill. A "clean air" sampling site was obtained from Site 8 located in the Tsitika River area above the Davie River at approximately 65 km east of Port Alice.

2.2 Sampling

2.2.1 Emissions Sampling

Emissions were sampled in the Acid Plant stack and the Recovery Furnace/Blowgas Absorption stack as specified in the emission permit (PA 3760). The emissions of the Recovery Furnace/Blowgas Absorption Stack were monitored continuously.[48] The Acid Plant stack emissions were determined approximately monthly under "normal" operating conditions. Normal operating conditions are defined in terms of approximating normal operating capacity (>450 ADU t/day pulp production). Particulate concentrations in the emissions are determined. However neither volume flow nor chemical composition are measured.

2.2.2 Air Quality Sampling

Sulphation plates are lead peroxide plates which are exposed to the atmosphere for a continuous thirty day period. The impingement of atmospheric sulphur compounds on these plates and their subsequent reaction with the lead peroxide, forms lead sulphate. The resulting quantity of lead sulphate is determined by laboratory analysis and is described as a Sulphation Index. This index is then used as a measure of the monthly absorption rate of atmospheric sulphur compounds.

The Sulphation Index was determined for 10 sites during 1981 and 1982. For each site, the Sulphation Index was transformed into an estimate of the mean monthly ambient concentration of SO_2 using an empirical formula.[77] These estimates of atmospheric SO_2 concentrations must be made with caution due to errors inherent to this methodology. Ambient concentrations of SO_2 can be estimated using sulphation plates to within 10-25% of actual concentrations.

The SO_2 monitor at Rumble Beach is a TECO 43 continuous gas analyzer which is operated by Western Forest Products Ltd. This analyzer has a detection range of 0-1335 $\mu g/m^3$ (0-0.5 ppm). SO_2 concentrations greater than this range cannot be quantified.

In 1981 the Waste Management Branch installed a TECO 43 continuous SO_2 gas analyzer at the Port Alice air quality monitoring site. From the time of installation to 1985, this analyzer had an observation range of 0-2660 $\mu g/m^3$ (1.0 ppm) and a sensitivity of 2.67 $\mu g/m^3$ (1 ppb). In 1985, the analyzer was replaced with a TECO 43 of similar sensitivity but with an observation range of 0-13,335 $\mu g/m^3$ (0-5.0 ppm).

2.2.3 Soil Sampling

At each of the sites, three soil horizons (and depths) were sampled. The surface LFH (forest litter, fibric and humic) horizon, and subsurface Bf_1 and Bf_2 horizons were sampled. Consistency of sampling and subsequent comparability of data were the reasons for selecting these horizons for sampling.

Soil samples, collected and placed in plastic bags, were initially taken to the dry laboratory in Victoria. Soil samples were immediately described by moist colour and hand texturing. They were then labelled and forwarded to the laboratory for analysis.

In the laboratory, samples were air dried. Suitable sub-portions as required for different analytical methods were taken from storage containers.

2.2.4 Vegetation Sampling

In as far as possible, the same species were sampled from each of the sites. With the exception of Site 4, branches of western hemlock were obtained from each site. Where possible, samples were also taken from other conifers, particularly, coast Douglas-fir and amabilis fir, which are expected to be highly sensitive to SO_2[15,16]. Mosses and lichens, where present, were also sampled.

Branches were collected from the canopy tops, where foliage is more directly exposed to the atmospheric currents, and from inside the canopy or the understory.

All plant names follow the conventions in Taylor and MacBryde[21].

2.3 Analysis

2.3.1 Information Sources

The history of the mill was obtained from Western Forest Products Ltd.[1]. Information on annual production and emission rates was provided by Environment Canada[90]. Air quality data were extracted from CAMIS[78] for the Port Alice monitor. Western Forest Products Ltd. provided the data for the monitor located in Rumble Beach. Information on monitoring history and permit conditions was obtained from the Regional Office of the Ministry of Environment in Nanaimo, and from permit files located in Victoria. Climate information was obtained from Atmospheric Environment Services, Environment Canada[42].

2.3.2 Emission Data Analysis

SO_2 emissions from the mill are estimated using monthly production information and emission rates. The method of estimation is presented in Section 3.1.

2.3.3 Air Quality Data Analysis

Air quality data is processed in accordance with the Environmental Laboratory procedures[79]. Data analysis uses standard report routines of CAMIS[78]. Sulphation plate data was analysed by the Environmental Laboratory and estimates of air quality were made using procedures of Lynch[77].

Because the Rumble Beach monitor was not capable of recording ambient SO_2 concentrations greater than 1335 $\mu g/m^3$, data from this analyzer will underestimate maximum and average concentrations.

Ambient air data can be used to describe temporal changes in air quality. However in the Port Alice area these data are influenced by fluctuating pollutant emission rates, changing local meteorological conditions, variable data availability, and changes in monitor observational limits. The lack of knowledge of local meteorological conditions and actual emission rates reduces the meaningfulness of the temporal variation measured at the monitoring sites.

2.3.4 Soils Data Analysis

Analysis of soil samples in this preliminary study was undertaken in order to allow assessment of soils relative to vegetation conditions, and of soil property changes which might have occurred due to exposure to high levels of sulphur dioxide over time.

Several properties were selected for analysis at this stage. These included:

- total sulphur and sulphate sulphur contents
- soil acidity
- measures or indicators of contents of elements which become more soluble as soil is acidified
- basic soil properties which characterize the soils and which are useful in interpreting the results.

Though analysis for sulphur contents was done, it was recognized that sulphur is not a conservative element in

soil. Losses to the atmosphere and uptake by plants, as well as leaching losses to lower soil depths and ground water may occur. Contents are, therefore, not entirely cumulative and will not fully reflect deposition over time. However, present levels of affected versus control areas, or levels in relation to exposure could be indicative of accumulation.

Analyses of samples were done by the Kelowna Soil and Tissue Testing Laboratory, British Columbia Ministry of Agriculture and Fisheries[29] (now, Griffin Laboratories Corporation). Properties for which analyses were done include the following:

- Sulphur

  - total sulphur
  - sulphate sulphur

- Measures or Indicators of Soil Acidity

  - pH in water
  - pH in 0.01M calcium chloride
  - exchangeable calcium
  - exchangeable magnesium
  - base saturation
  - lime requirements (to pH 5.4, 5.5, 6.0, 6.5)

- Elements Which Become More Soluble with Acidification

  - extractable copper
  - extractable iron
  - extractable manganese

- extractable zinc
- extractable boron
- exchangeable aluminum

- Basic Soil Properties Used to Characterize Soils

  - water content
  - total carbon (measure of organic matter)
  - cation exchange capacity
  - exchangeable bases (Ca, Mg, Na, K)
  - total nitrogen
  - nitrate nitrogen
  - extractable available phosphorus
  - carbon/nitrogen ratio
  - sodium pyrophosphate extractable iron
  - sodium pyrophosphate extractable aluminum
  - citrate bicarbonate dithionite extractable iron
  - citrate bicarbonate dithionite extractable aluminum
  - ammonium oxalate extractable iron
  - ammonium oxalate extractable aluminum
  - electrical conductivity (salt content)
  - exchangeable sodium percent
  - sodium adsorption ratio

Analytical methods for most parameters are as described in McKeague[52]. Further details of methods used may be determined by reference to: B.C. Soil Information System. Soil Laboratory Test Parameters (unpublished) and B.C. Soil Information System, Soil Laboratory Test Method Dictionary[53], available from the B.C. Ministry of Environment.

Data were analyzed as follows:

- tabulation of laboratory results for comparison to site characteristics.

- graphical analysis of selected parameter values for both surface and subsurface horizons in relation to distance from the mill.

- graphical analysis of relationships between selected analytical parameters to allow appreciation of covariation and possible attribution of causes.

- comparison of analytical values for soils from this study with values form other studies in B.C. and other areas.

- comparison of soil and vegetation analytical values to show relationships which might exist and thus show effects on vegetation of soil conditions in addition to direct foliar impacts.

Computer graphical methods involved use of the graphics module of the integrated package "Synergy" on a Digital Equipment Corporation (DEC) 350 desktop computer.

2.3.5 Vegetation Data Analysis

For each sample the branches were partitioned into current year's growth (YR0) and subsequent years (YR1, YR2, etc.). Where several years were combined, the sample was designated with a "+" after the most recent growth year in the sample (YR4+) (see Plates A.3.20, A.3.37B, A.3.38). Partitioning

was based on existence of current year's growth, annual "bud ridges", and comparison of color and texture of the sections of the stems.

All samples were dried at 40°C for at least 48 hours. Some samples (amabilis fir) required an additional 48 hours of drying to remove all moisture.

Foliage was manually separated from twigs inside a clear plastic bag to prevent loss of tissue. The dry weight of stems and foliage were determined. A dry-weight foliage:twig ratio was calculated.

The tissues were analyzed for total sulphur content using a Nitric Perchloric Acid Digestion with sulphur determined by means of an Inductively-Coupled Argon-Platinum Spectrophotometer[17] in the Soil, Feed, Tissue and Water Laboratory, B.C. Ministry of Agriculture and Food in Kelowna.

Information on the production history of the Port Alice pulpmill and its present production and control of SO_2 emissions was obtained from Western Pulp Inc. Ltd. in Port Alice (now Western Forest Products Ltd.).

Data on air quality at the monitoring site Port Alice (0110501) for the period February 1981 to February 1986 inclusive were obtained from Continuous Air Monitoring Information System (CAMIS) of the Ministry of Environment. The measurements were taken with a TECO 43 SO_2 Analyzer.

To determine if critical droughts were likely to have occurred, information on long-term climatic extremes was obtained from Ministry of Environment, Meteorological

Services[20]. Information on insect and disease infestations in the area was obtained from Environment Canada, Forest Insect and Disease Survey[18,19].

Regression analysis of air quality information was accomplished using a GLM procedure of SAS release 5.08[22,23].

CHAPTER THREE
DATA AND RESULTS

3.1 Emissions

Ambient SO_2 concentrations were not measured prior to 1981. However, atmospheric emissions will bear a general relationship to the daily production rates of the mill. These are presented in Table 3.1.1. The Port Alice pulpmill started production in 1918 with 2 digesters producing approximately 45 metric tons of pulp per day. The mill expanded in stages until in 1968 it reached its maximum size with 8 digesters on line with a daily production of 375 tons. In 1972 the process was slightly modified by switching from the Calcium-based cooking acid to an ammonium-based cooking acid in preparation for the installation of the Spent Liquor Recovery System (SSL) in 1978. In 1980 the blow gases from the digesters were rerouted into the recovery boiler and stack. In 1983 a Brink's filter was installed on the recovery boiler stack to reduce particulate emissions. With the present configuration, a production target of 420 metric tons has been set.

Monthly emission rates for the Recovery Furnace/Blowgas Absorption (Recovery Boiler Stack) and the Acid Plant stack are presented in Table 3.1.2 for the period 1981 to 1986. Corresponding production figures for the period 1981 to 1987 are presented in Table 3.1.3. Estimated annual emissions of SO_2 are summarized in Table 3.1.4.

The estimation of SO_2 emission rates is subject to a significant inherent error[48,49]. The calculated estimates must therefore be used with discretion.

Monthly summaries of emissions and production are presented in Tables 3.1.2 to 3.1.4.

3.2 Air Quality

The annual mean Sulphation Index and estimated annual SO_2 concentration for 1981 and 1982 (Table 3.2.3) have been calculated by Leung[50].

Maximum monthly sulphur dioxide concentrations were recorded during 1981 and 1982 by sulphation plates located 1.2 km northwest of the Port Alice pulpmill. They ranged from 149 to 318 $\mu g/m^3$. The uncertainty in sulphation plate data is ± 25% and as a consequence all of the sulphation plate sites may have exceeded the one year, "B" level, ambient air objectives during both years of observations (Table 3.2.3).

Annual SO_2 concentrations, which were determined using the monthly Sulphation Index data, decreased with increasing distance from the Port Alice pulp mill.

Hourly SO_2 concentrations have been monitored near the Port Alice pulp mill since 1981. The potential number of hourly observations in a year is 8760 (8784 in a leap year). The annual data capture rate ranged from a low of 38% during 1981 to 98% during 1983; in other years the percentage ranged between 66% and 93% (Figure 3.2.1).

Average concentrations and maximum concentrations at the Port Alice monitoring site are determined for 1986 and 1987.

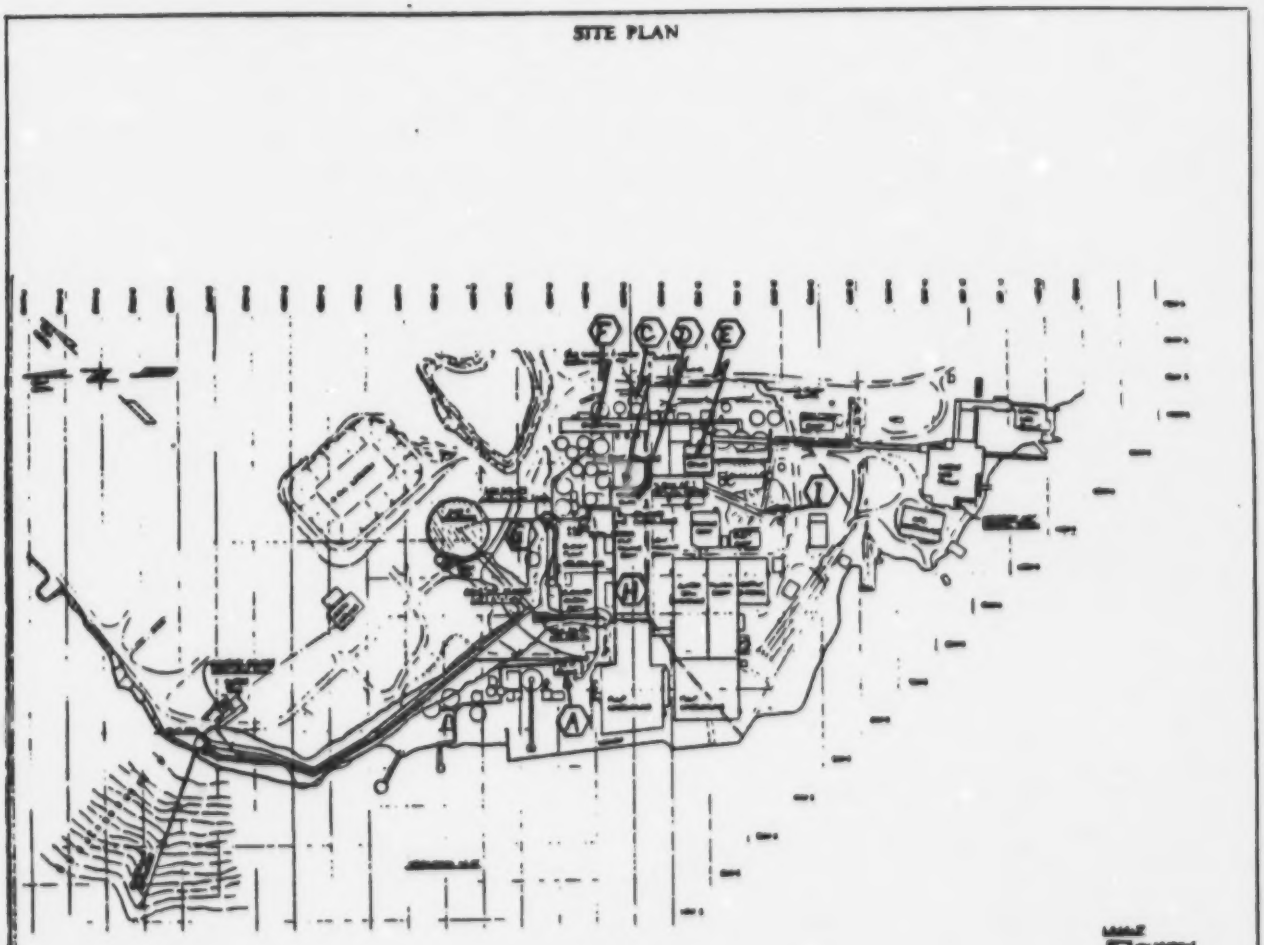
TABLE 3.1.1
PORT ALICE SULPHITE MILL HISTORY
(From Western Pulp Inc. Ltd.)

Year	Ownership	Daily Production	Comments
1904	Oriental Power and Pulp Co.	--	Received timber leases
1916	Colonial Pulp and Paper	--	
1917	Whalen, B.C. Sulphite Co.	--	Included Woodfibre Swanson Mill
1918	Whalen Pulp and Paper Co.	45 m tons	2 digesters
1919		90 m tons	3 digesters
early 20's	in receivership	--	
1925	B.C. Pulp and Paper Co. Ltd.	--	
1926		140 m tons	4 digesters; Calcium based cooking acid using local limestone
1942		180 m tons	5 digesters
1951	Abitibi Power and Paper, Alaska Pine & Cellulose Co. Ltd.	--	mill upgraded
1957	Rayonier Canada Ltd.	280 m tons	6 digesters
1960		320 m tons	7 digesters
1963		360 m tons	8 digesters on line
1968	ITT, Rayonier Canada (B.C.) Ltd. Subsidiary	375 m tons	new equipment, new bleaching
1972		--	switched to NH_3 based cooking acid in preparation for spent liquor recovery system (SSL)
1978	Rayonier Canada Ltd.	--	SSL recovery system in place, affecting SO_2 emissions
1980	Western Forest Products Ltd.	--	digester blow gas connected into recovery boiler and stack
1981 (July)	ashes trench burner	--	fugitive dust 290 $\mu g/dm^2/day$
1983 (December)	Western Pulp Inc.	--	burner dismantled; particulate emissions controlled by installation of Brink's filter on recovery boiler stack; hog fuel firing boiler rebuilt; hog fuel handling and drying improved
Present	Western Forest Products Ltd.	460 m tons	

Permits:	PR1634	July 17, 1972	Amended: Nov. 25, 1976 Feb. 23, 1981
	PA3760	April 27, 1978	Amended: July 10, 1981
	PE1240	March 3, 1973	Amended: July 26, 1979 Dec. 21, 1981 Variance: June 29, 1983

Figure 3.1.1

Western Forest Products Ltd. Sulphite Pulp Mill Emission Source Points



The discharges originate at Lots 1187 and 1188 Rupert District, on the shore of Neroutsos Inlet Quatsino Sound, vicinity of Port Alice.

A - Acid Plant (SO_2)
C - Oil-Fired Power Boiler (particulates, SO_2)
D - Wood-Waste Burning Power Boiler (particulates)
E - Recovery Furnace/Blow Gas Absorption (particulates, SO_2)
G - Bleach and Chemical Plant (Chlorine, Chlorine dioxide)
H,I-Miscellaneous Sources

Table 3.1.2

PORT ALICE SULPHUR DIOXIDE EMISSION RATES

	1981		1982		1983	
MONTH	RECOVERY BOILER STACK (kg/ADUT)	ACID PLANT STACK (kg/ADUT)	RECOVERY BOILER STACK (kg/ADUT)	ACID PLANT STACK (kg/ADUT)	RECOVERY BOILER STACK (kg/ADUT)	ACID PLANT STACK (kg/ADUT)
JAN	8.1	0.27	-	0.04	44.9	1
FEB	4.9	0.02	-	-	21.2	0.06
MAR	5.8	-	-	-	23.8	0.5
APR	10.9	-	-	0.05	21.3	0.27
MAY	11.0	0.007	-	0.06	22	0.13
JUN	8.8	0.02	-	0.05	39.6	0.17
JUL	-	0.003	10.2	-	65.4	0.14
AUG	-	-	-	0.5	42.8	0.12
SEP	15.2	0.7	-	-	20.4	1.1
OCT	-	1.42	7.1	0.1	15.3	0.1
NOV	-	0.006	9.3	0.9	34	0.14
DEC	-	0.003	12.6	0.17	32.8	0.07
AVERAGE	9.2	0.3	9.8	0.2	32.0	0.3

	1984		1985		1986	
MONTH	RECOVERY BOILER STACK (kg/ADUT)	ACID PLANT STACK (kg/ADUT)	RECOVERY BOILER STACK (kg/ADUT)	ACID PLANT STACK (kg/ADUT)	RECOVERY BOILER STACK (kg/ADUT)	ACID PLANT STACK (kg/ADUT)
JAN	33.7	0.05	-	4.4	41.1	0.105
FEB	-	-	25.9	3.3	33.8	-
MAR	-	-	25.5	-	-	0.688
APR	-	0.025	30.1	0.19	46.5	1.38
MAY	34.4	0.08	25.6	-	38.3	0.32
JUN	-	1.5	24	3.1	38.8	3.1
JUL	-	0.33	33.5	1.1	43.1	0.07
AUG	24.2	0.36	38.8	1.2	55.5	-
SEP	32.2	0.06	34	-	62.4	-
OCT	24.6	2.35	37.5	2.46	-	-
NOV	18.5	0.02	27.1	3	-	2.16
DEC	-	1	31.2	-	38.4	0.149
AVERAGE	27.9	0.6	30.3	2.3	44.2	1.0

figures summarized from Western Pulp Limiteds' "Source Monitoring Quarterly Reports"

Table 3.1.3

PORT ALICE PRODUCTION FIGURES (in air dried, bleached metric tons)

	1981		1982		1983		1984	
MONTH	PRODUCTION (ADT/day)	NUMBER OF DAYS	PRODUCTION (ADT/day)	NUMBER OF DAYS	PRODUCTION (ADT/day)	NUMBER OF DAYS	PRODUCTION (ADT/day)	NUMBER OF DAYS
JAN	400	27	397	18	440	18	413	22
FEB	426	28	s.d.	0	458	18	s.d.	0
MAR	409	28	408	17	431	19	s.d.	0
APR	428	21	413	18	452	18	391	18
MAY	372	28	440	27	437	20	459	23
JUN	426	28	443	15	471	19	443	28
JUL	441	20	418	9	410	20	398	29
AUG	s.d.	0	385	14	401	20	431	28
SEP	310	24	398	9	388	20	414	29
OCT	403	28	437	18	415	28	444	27
NOV	404	30	467	18	388	26	429	24
DEC	371	12	461	14	424	24	451	18
yearly total (ADT)		109628		75501		106042		105103
+10%		120591		83051		116646		115613

	1985		1986		1987	
MONTH	PRODUCTION (ADT/day)	NUMBER OF DAYS	PRODUCTION (ADT/day)	NUMBER OF DAYS	PRODUCTION (ADT/day)	NUMBER OF DAYS
JAN	362	24	395	24	393	28
FEB	426	28	443	24	485	28
MAR	389	16	392	20	461	31
APR	421	21	426	26	467	29
MAY	347	16	411	29	481	19
JUN	385	24	463	29	425	30
JUL	390	29	446	27	473	31
AUG	404	27	451	31	479	31
SEP	419	26	423	24	469	26
OCT	405	16	410	29	466	31
NOV	403	30	434	30	470	30
DEC	342	17	427	29	485	24
yearly total (ADT)		107969		137842		156199
+10%		118766		151626		171819

note: to convert bleached figures to unbleached, 10% was added to yearly totals

Table 3.1.4 Estimated Production and Emission

Year	Daily Production[1] (ADt/d)	#Days of[2] Operation	Emissions[3] of SO_2 (kg/ADUt)	Production[4]	Emissions SO_2 kgX10[6]
1981	400	274	9.5	120591	1.146
1982	424	177	10.0	83051	0.831
1983	417	250	32.3	116646	3.768
1984	427	246	28.5	115613	3.295
1985	394	274	32.6	118766	3.872
1986	428	322	45.2	151626	6.853
1987	462	338	*	171819	*

1 From Environment Canada. Production is recorded daily and averaged for Daily Production Rate. Note that where Production is reported in ADt (ie. bleached) an increment of 10% is applied to approximate ADUt (unbleached) production of pulp.

2 From Environment Canada and/or Western Pulp Ltd. source monitoring quarterly reports. Indicating the number of days for which daily production is recorded.

3 Average Emission rates for the Recovery Boiler stack and the Acid Plant stack were determined from monthly emission rates. The average may be based on less than 12 months of data per year. The Emission Rates for the Recovery Boiler stack are determined from "more or less" continuous monitoring and daily production rates. Those for the Acid Plant stack are estimated from one or few arbitrary monthly measurements under "normal operating conditions" (better: Standard conditions). The Emission Rate is the sum of that of the Acid Plant stack and the Recovery Boiler stack. Sulphur from other Emission points is not included.

4 Production is estimated as the sum of the monthly product of Daily Production Rates and Number of Operating Days. A 10% conversion from bleached (ADt) to unbleached (ADUt) pulp yield is applied.

5 Annual SO_2 Emission estimates are obtained as the product: Emission Rate (kg SO_2/ADUt) X Production (ADUt).

* Data is not presently available.

Prior to this period the SO_2 monitor was unable to record concentrations greater than 2660 µg/m^3. Zero concentration values (ie. readings below detection limit) occur between 58% and 66% of the time at this Site.

Air Quality Objectives British Columbia are presented in Table 3.2.1.

Table 3.2.1
Air Quality objectives for Sulphur Dioxide (µg/m^3)

Averaging Period	"A" Level [93,94]	"B" Level [93,94]	"C" Level [94]
1-hour	450	900	
24-hour	160	260	360
1-year	25	50	80

Note that "A" Level and "B" Level are identical for forest industry and agriculturally oriented industry. "C" Level is defined for the latter.

During 1986 and 1987 the average monthly 1-hour concentrations ranged from 110 to 350 µg/m^3 (Figure 3.2.2). One-hour maximum concentrations for each month of this two year period ranged from 2000 µg/m^3 (2.2 times the 1-hour "B" Level ambient air SO_2 objective), to 9400 µg/m^3 (more than ten times "B" Level ambient air objectives) (Figure 3.2.3). One-hour monthly maximums averaged around 5000 µg/m^3 more than 5.5 times "B" Level objectives.

Monthly Maximum 24-hour average concentrations exceed 24-hour "B" Level objectives during most months of the 1986-1987 period (Figure 3.2.4). Maximums range from 325 $\mu g/m^3$ (1.25 times greater than 24-hour "B" Level objectives) to about 1900 $\mu g/m^3$ (more than 7 times greater than the 24-hour "B" Level, and 2 times greater than the 24-hour "C" Level, ambient air objectives).

The number of 1-hour, "B" Level, ambient air exceedances (900 $\mu g/m^3$) observed at the Port Alice site indicates that, at this location, "B" Level exceedances ranged from 56 in 1981 to 395 in 1986 (Table 3.2.1; Figure 3.2.5), and the mean annual number of 1-hour, "B" Level exceedances over the period of record is 279.

The number of 24-hour "B" Level exceedances (260 $\mu g/m^3$) ranged from 9 in 1981, to 93 in 1983 (Table 3.2.1; Figure 3.2.6). Over the monitoring period, the mean annual number of 24-hour, "B" Level exceedances is 62.

The number of 24-hour, "C" Level, SO_2 exceedances (800 $\mu g/m^3$) observed at the Port Alice Monitoring site, ranged from 0 in 1984, to 8 in 1985 and 1986 (Figure 3.2.7).

The relative frequency distribution of hourly concentration observations (Table 3.2.2) for Port Alice, indicates a greater number of zero concentration values in the 1986-1987 period than during the previous years and that this was somewhat offset by a decrease in concentrations which fall into the >10-452 class. It may be due to meteorological variability between years, and possibly influenced by

variable pulpmill emission rates. Meteorological data are required to verify this hypothesis.

Because of the inherent uncertainty in SO_2 concentration estimates using sulphation plates, no significant difference in plate-monitored air quality can be demonstrated between the 1981 and 1982 monitoring periods. Since the sulphation plates were not operated subsequent to 1982, no assessment is possible for later years.

Comparisons of exceedance data over the years are subject to the same constraints as other temporal air quality analyses for the Port Alice area (see 2.2.3).

The monthly numbers of 1-hour "B" Level exceedances for the 1981 through 1987 period at Port Alice are shown in Figure 3.2.8. The number of observed exceedances is influenced by the total number of observations made in the year so that direct comparisons between years and months is not feasible. When available the number of observed exceedances tends towards a greater number of 1-hour, "B" Level exceedances in the 1985 to 1987 period.

A general seasonal pattern in 1-hour, and 24-hour, "B" Level exceedances can be seen in figures 3.2.8 and 3.2.9. Lower numbers of exceedances tend to occur during the winter and monthly totals progressively increase thereafter to reach a peak in late summer or early fall. The cause of such patterns may be related to meteorological events, but this cannot be verified because of a lack of appropriate meteorological data.

Table 3.2.2

PORT ALICE SULPHUR DIOXIDE EXCEEDANCES–BY YEAR

		NUMBER OF EXCEEDANCES			
YEAR	1-hr "A"	1-hr "B"	24-hr "A"	24-hr "B"	24-hr "C"
1981	165	56	26	9	1
1982	700	302	102	68	3
1983	976	393	155	93	7
1984	335	86	65	23	0
1985	912	379	126	78	8
1986	877	395	132	87	8
1987	918	345	136	76	3

Table 3.2.3

PORT ALICE–RELATIVE FREQUENCY DISTRIBUTION OF HOURLY SO2 CONCENTRATIONS

CONCENTRATION (µg/m3)	FREQUENCY(%)						
	1981	1982	1983	1984	1985	1986	1987
'=0	42.41	52.40	36.26	44.88	42.61	58.51	65.81
0-452	52.72	39.91	52.54	49.93	44.85	26.31	23.11
453-904	3.31	4.62	7.18	3.99	7.92	8.34	6.92
905-1357	0.88	1.95	2.44	0.82	3.12	3.74	2.38
1358-1810	0.43	0.57	0.85	0.22	1.14	1.07	0.87
1811-2263	0.12	0.28	0.34	0.10	0.27	0.67	0.42
2264-2660	0.12	0.27	0.38	0.06	0.09		
>2660	*	*	*	*	*		
2264-2715						0.50	0.17
2716-3168						0.14	0.11
3169-3621						0.31	0.10
3622-4073						0.12	0.02
4074-4526						0.05	0.04
4527-4979						0.05	0.01
4980-5432						0.05	0.00
5433-5884						0.02	0.00
5885-6337						0.00	0.01
6338-6790						0.09	0.02
6790-7242						0.00	0.00
7243-7695						0.00	0.01
7696-8148						0.00	0.00
8149-8601						0.00	0.00
8602-9053						0.00	0.00
9054-9506						0.02	0.00
TOTAL	100.00	100.00	100.00	100.00	100.00	100.00	100.00

* not included in totals

Table 3.2.4

SULPHATION INDEX AND ESTIMATED SULPHUR DIOXIDE CONCENTRATIONS IN 1981 AND 1982

STATION	DISTANCE FROM PULP MILL	MEAN ANNUAL SULPHATION INDEX (mg/dm2/day)		ESTIMATED ANNUAL SULPHUR DIOXIDE CONCENTRATION (µg / m3)					
		1981	1982	1981			1982		
				(-25%)		(+25%)	(-25%)		(+25%)
1	1.0 km SE	0.22	0.20	23	31	39	21	28	35
2	0.9 km E	0.47	0.65	49	65	81	68	90	113
3	1.8 km E	0.23	0.34	24	32	40	35	47	59
4	1.2 km NW	1.82	1.43	191	254	318	149	199	249
5	2.0 km NW	1.14	1.04	119	159	199	109	145	181
6	2.5 km NW	1.22	0.97	128	170	213	101	135	169
7	3.3 km NW	1.07	0.97	112	149	186	101	135	169
8	4.2 km NW	0.39	0.37	41	54	68	39	52	65
9	5.2 km NW	0.29	0.30	30	40	50	32	42	53
10	5.8 km NW	0.22	0.19	30	40	50	20	26	33

FIGURE 3.2.1

AMOUNT OF HOURLY SO2 DATA AVAILABLE--BY YEAR FOR 1981-1987

(EXPRESSED AS A PERCENTAGE FRACTION OF MAXIMUM POSSIBLE)

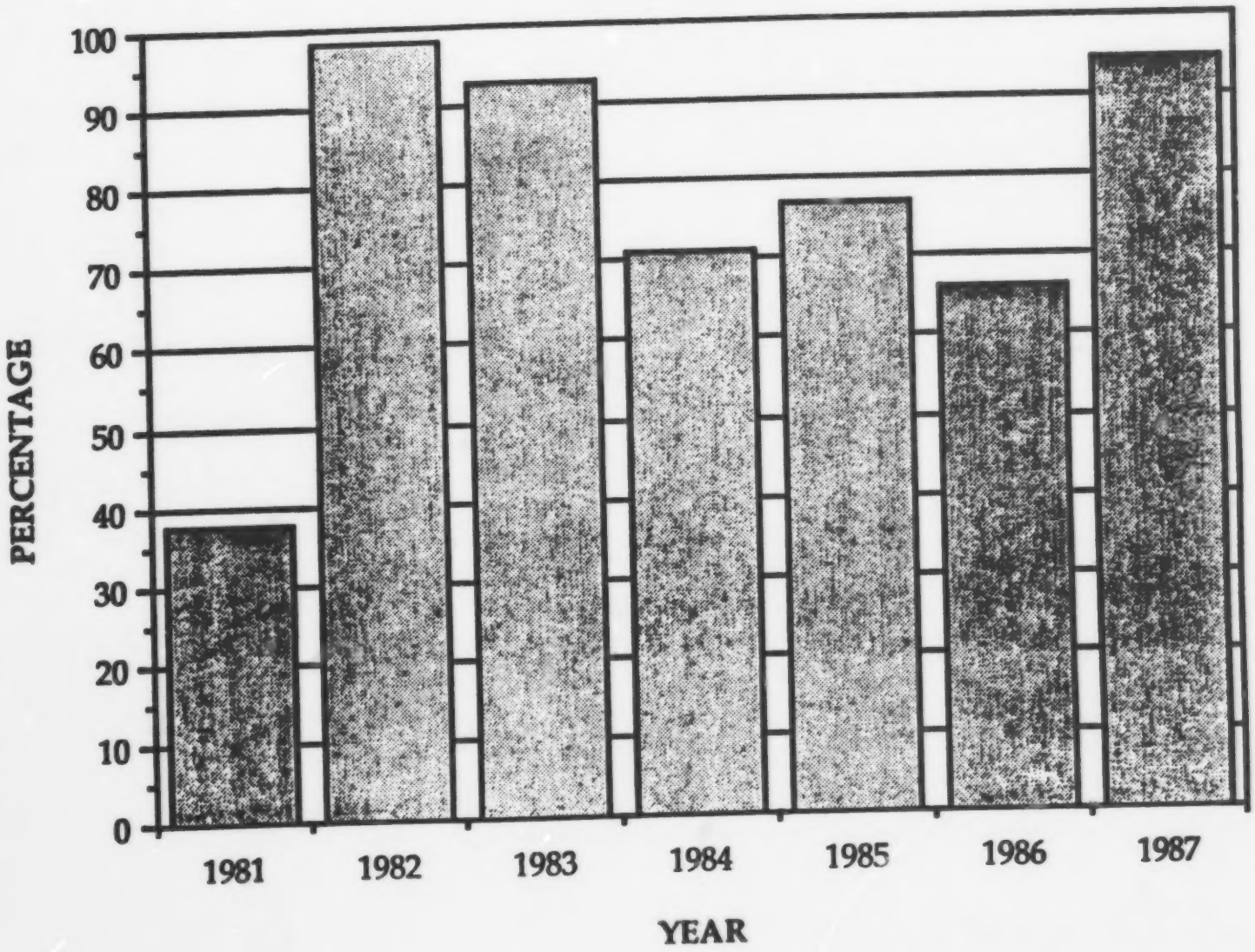
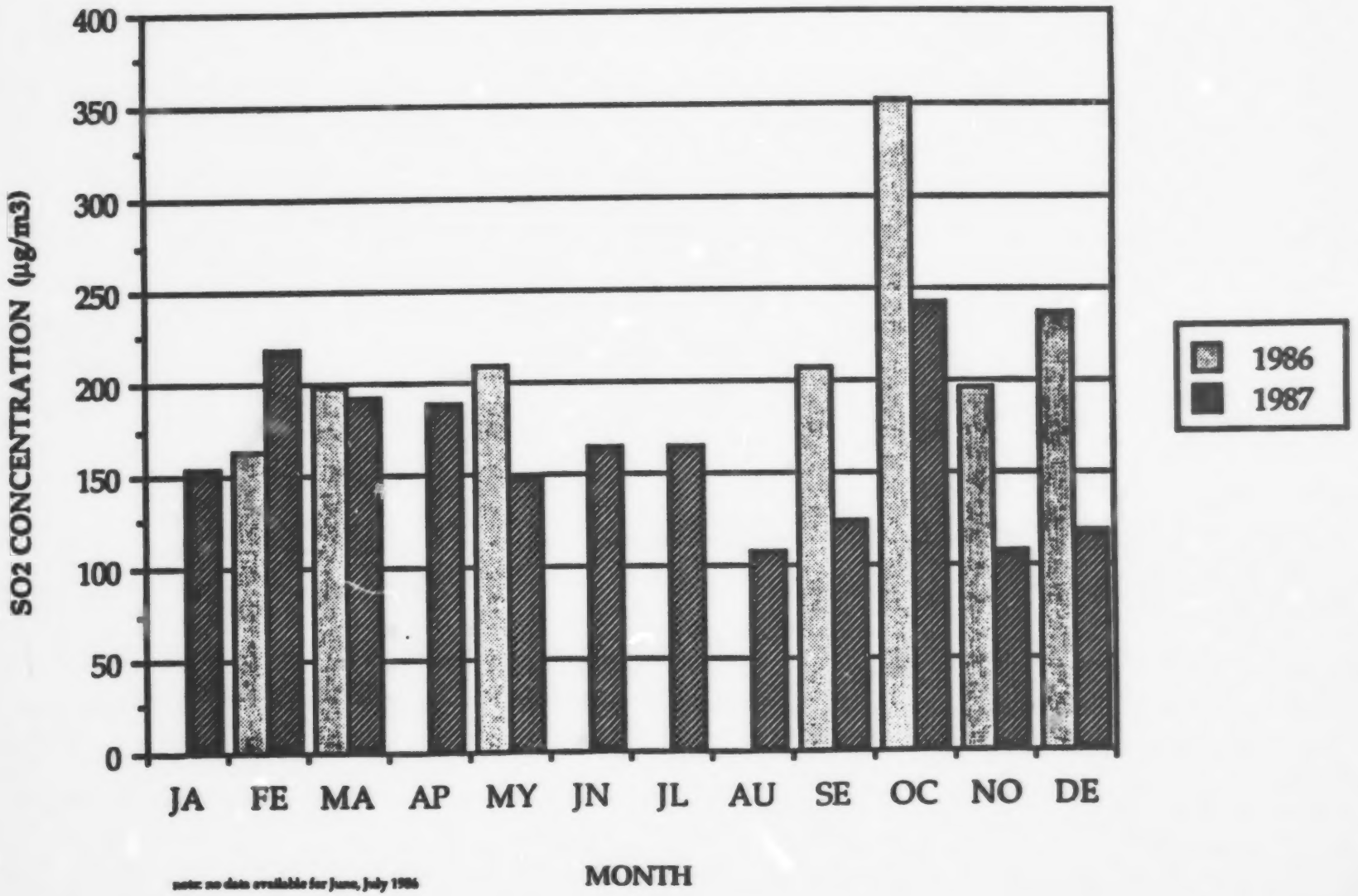


FIGURE 3.2.2 **PORT ALICE--SULPHUR DIOXIDE**

AVERAGE 1-HOUR CONCENTRATION--BY MONTH FOR 1986-1987

(zero values included in averaging)



note: no data available for June, July 1986

FIGURE 3.2.3 **PORT ALICE–SULPHUR DIOXIDE**

MAXIMUM 1-HOUR CONCENTRATION–BY MONTH FOR 1986-1987

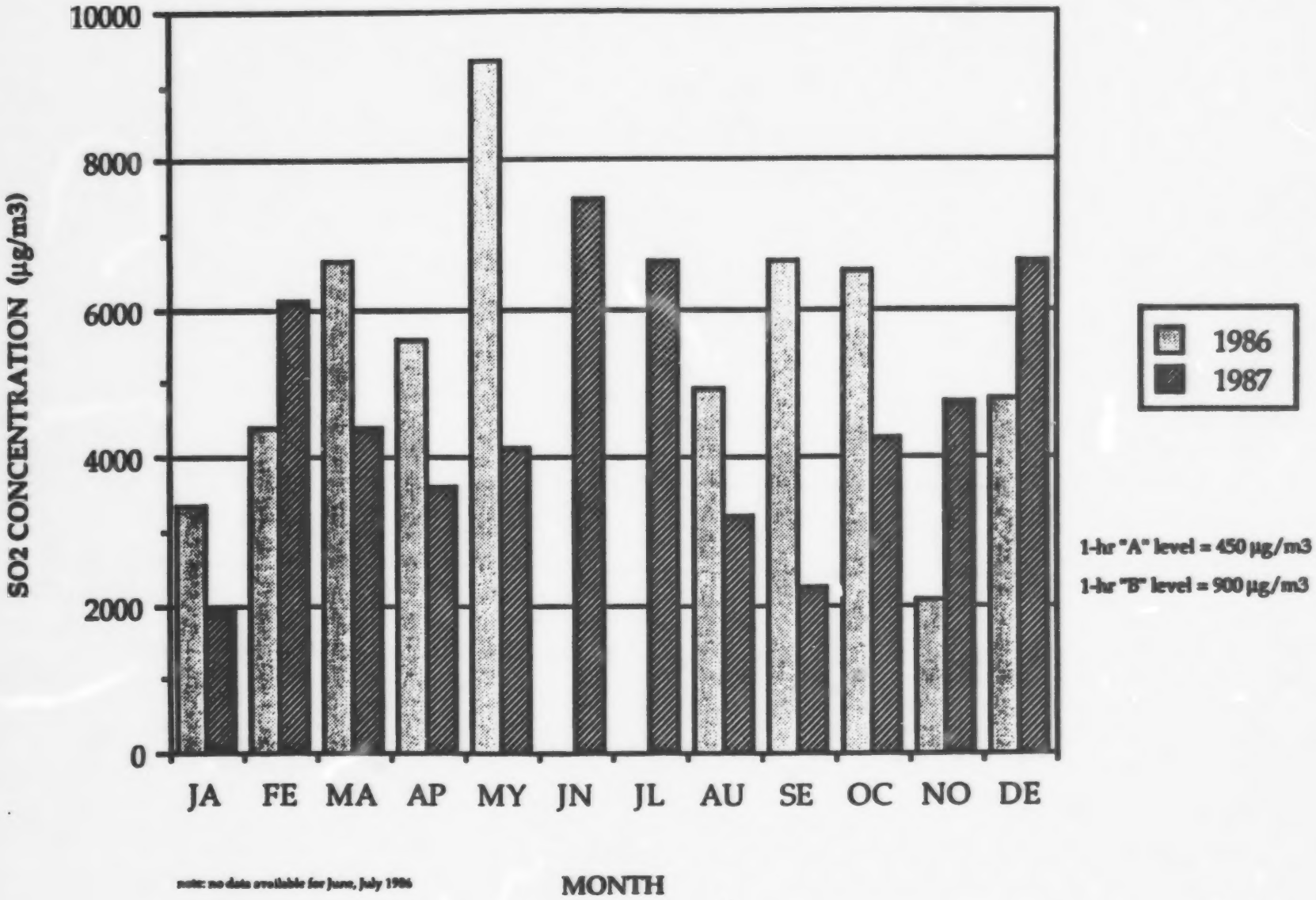
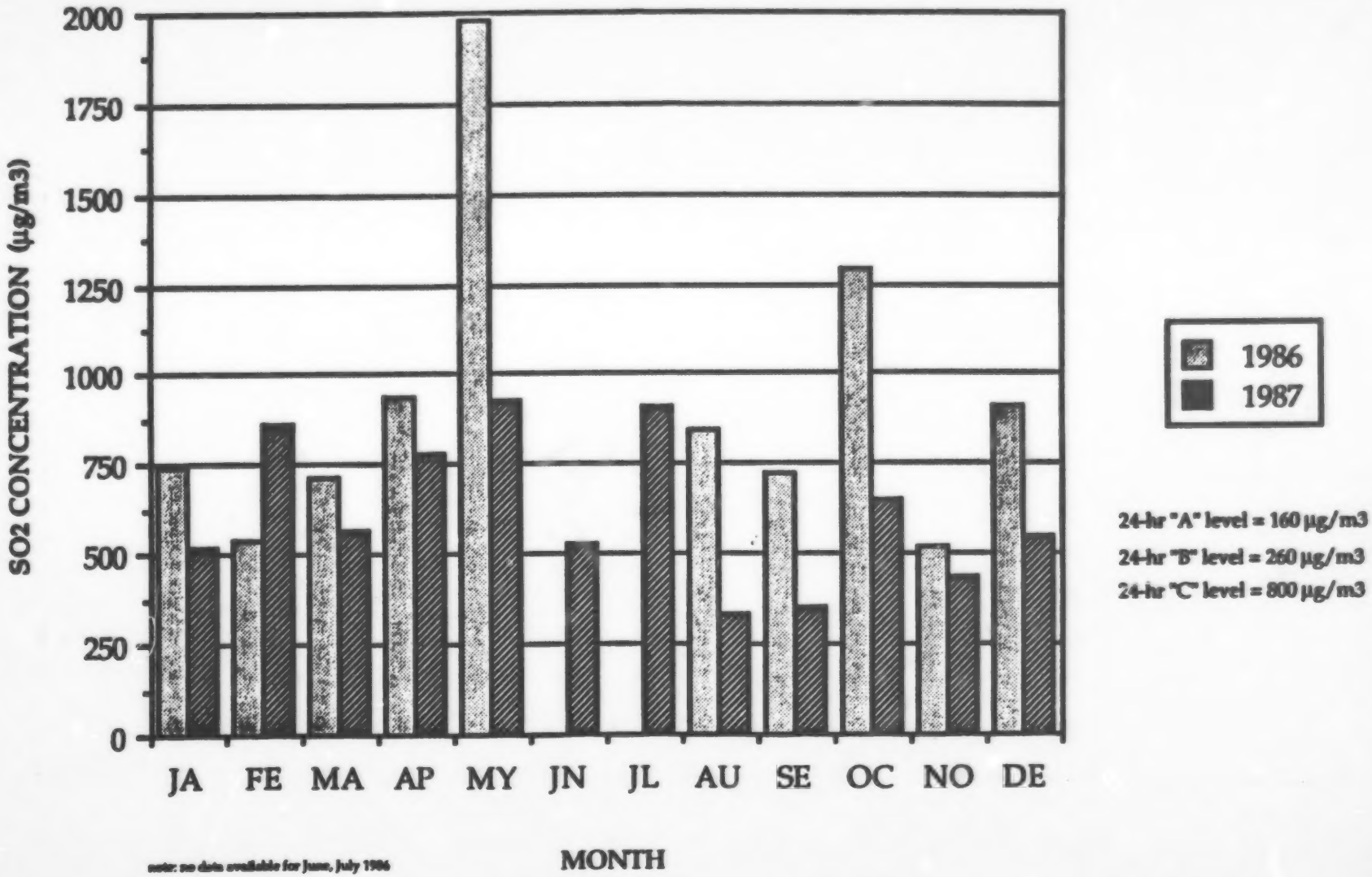


FIGURE 3.2.4 **PORT ALICE--SULPHUR DIOXIDE**

MAXIMUM 24-HOUR AVERAGE CONCENTRATION--BY MONTH FOR 1986-1987



note: no data available for June, July 1986

FIGURE 3.2.5 **PORT ALICE–SULPHUR DIOXIDE**
NUMBER OF 1-HOUR "B" LEVEL EXCEEDANCES–BY YEAR FOR 1981-1987

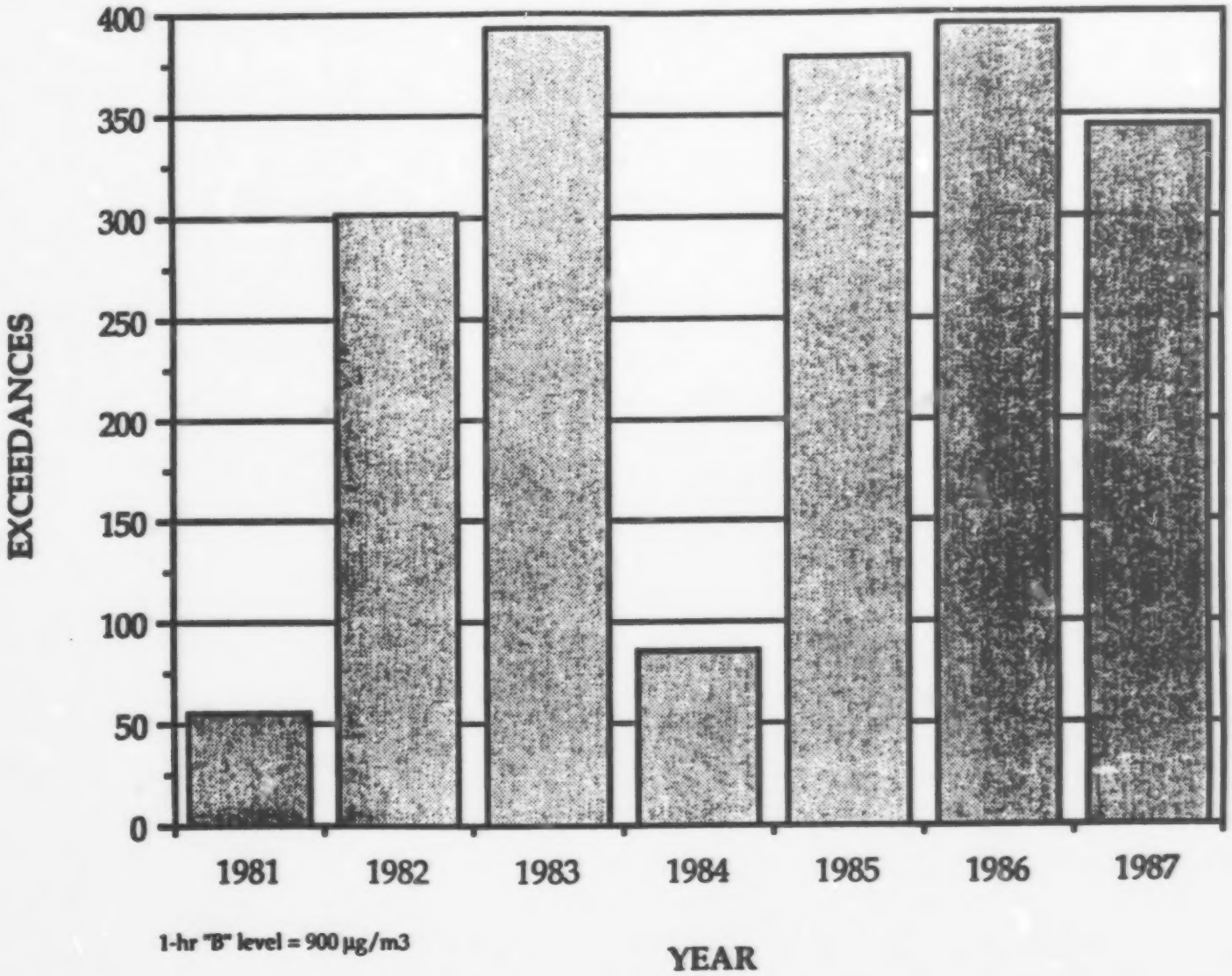
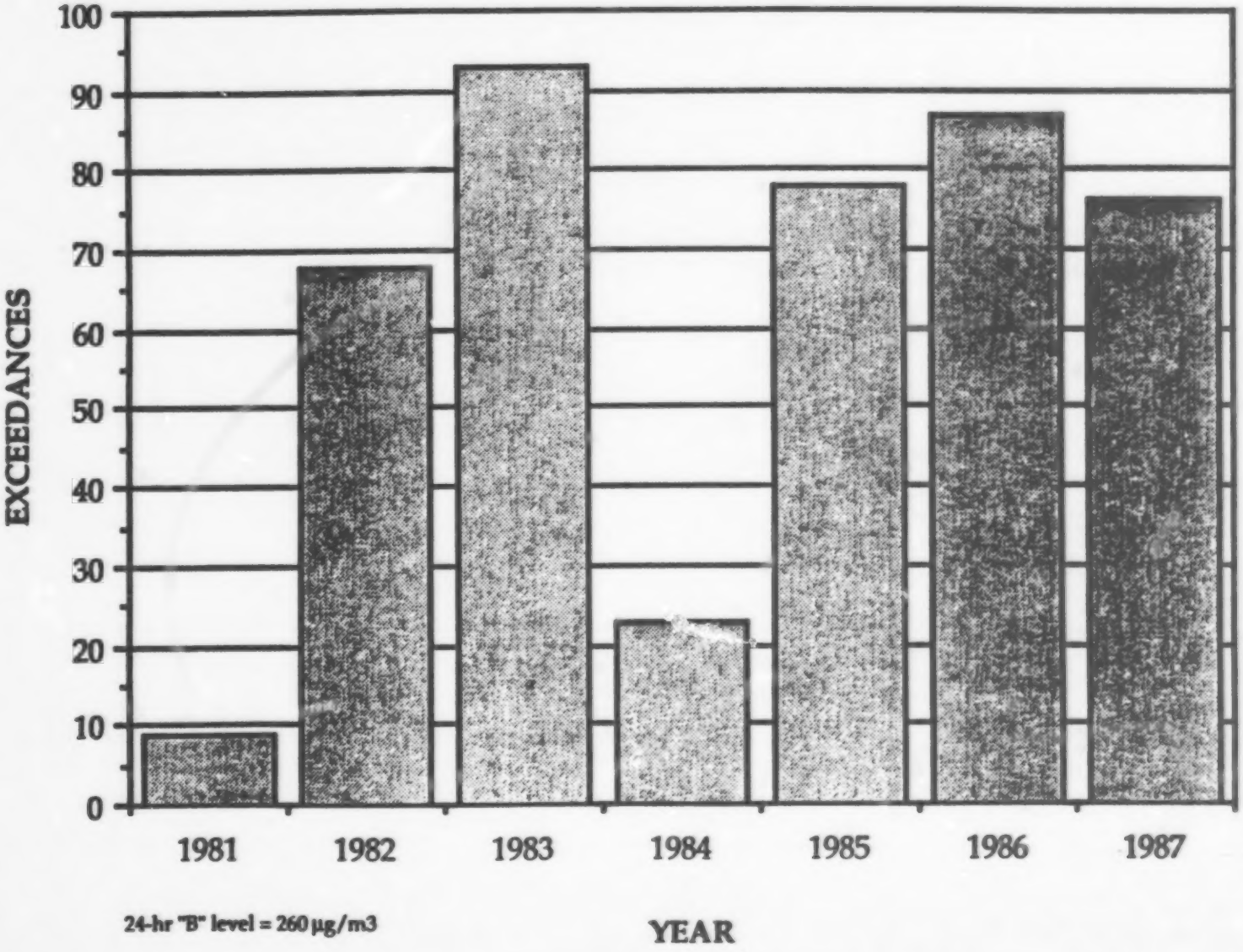


FIGURE 3.2.6 **PORT ALICE--SULPHUR DIOXIDE**

NUMBER OF 24-HOUR "B" LEVEL EXCEEDANCES--BY YEAR FOR 1981-1987



24-hr "B" level = 260 µg/m3

FIGURE 3.2.7

PORT ALICE--SULPHUR DIOXIDE

NUMBER OF 24-HOUR "C" LEVEL EXCEEDANCES--BY YEAR FOR 1981-1987

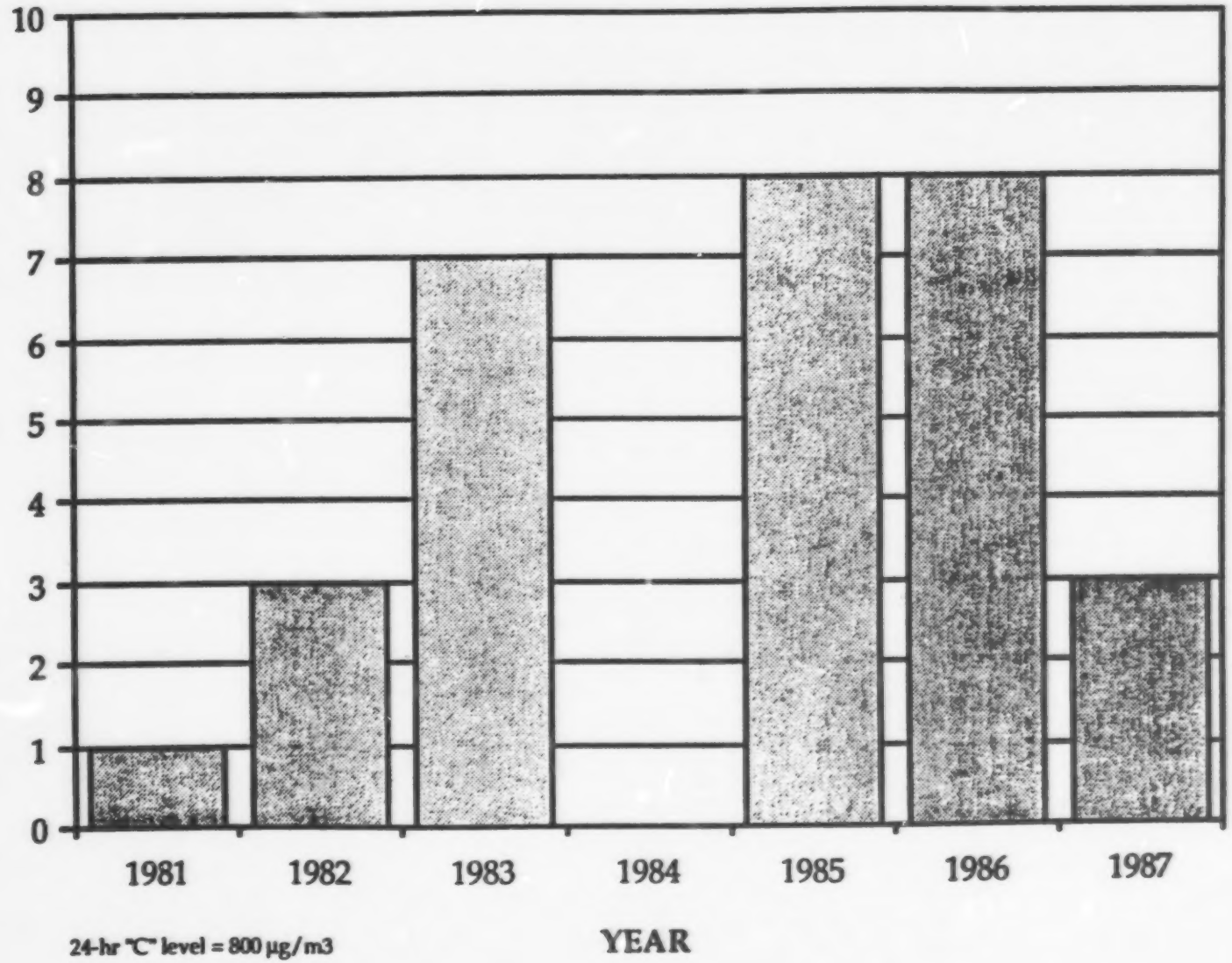
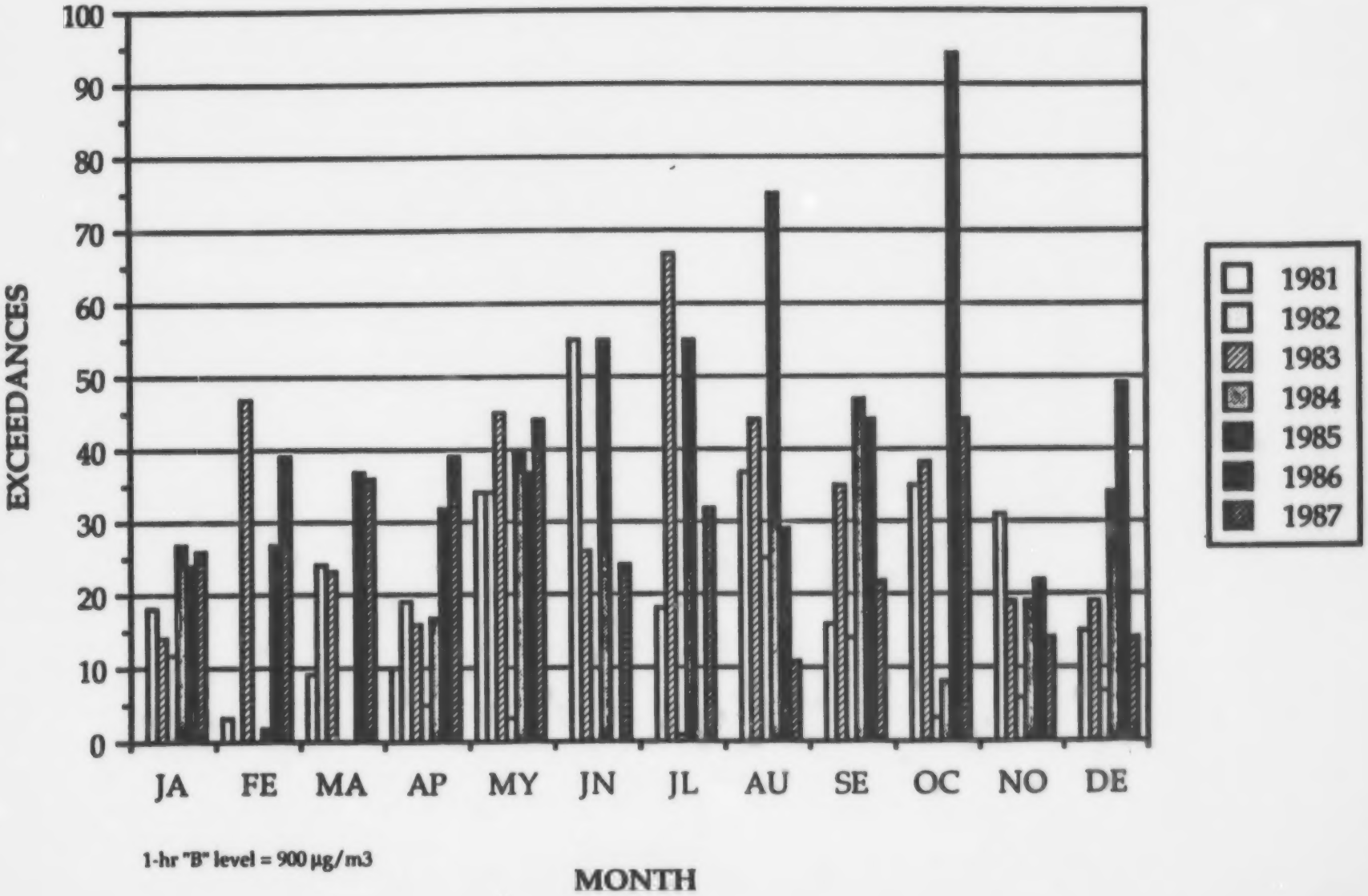


FIGURE 3.2.8 **PORT ALICE--SULPHUR DIOXIDE**

NUMBER OF 1-HOUR "B" LEVEL EXCEEDANCES--BY MONTH FOR 1981-1987



1-hr "B" level = 900 µg/m3

FIGURE 3.2.9 **PORT ALICE–SULPHUR DIOXIDE**

NUMBER OF 24-HOUR "B" LEVEL EXCEEDANCES–BY MONTH FOR 1981-1987

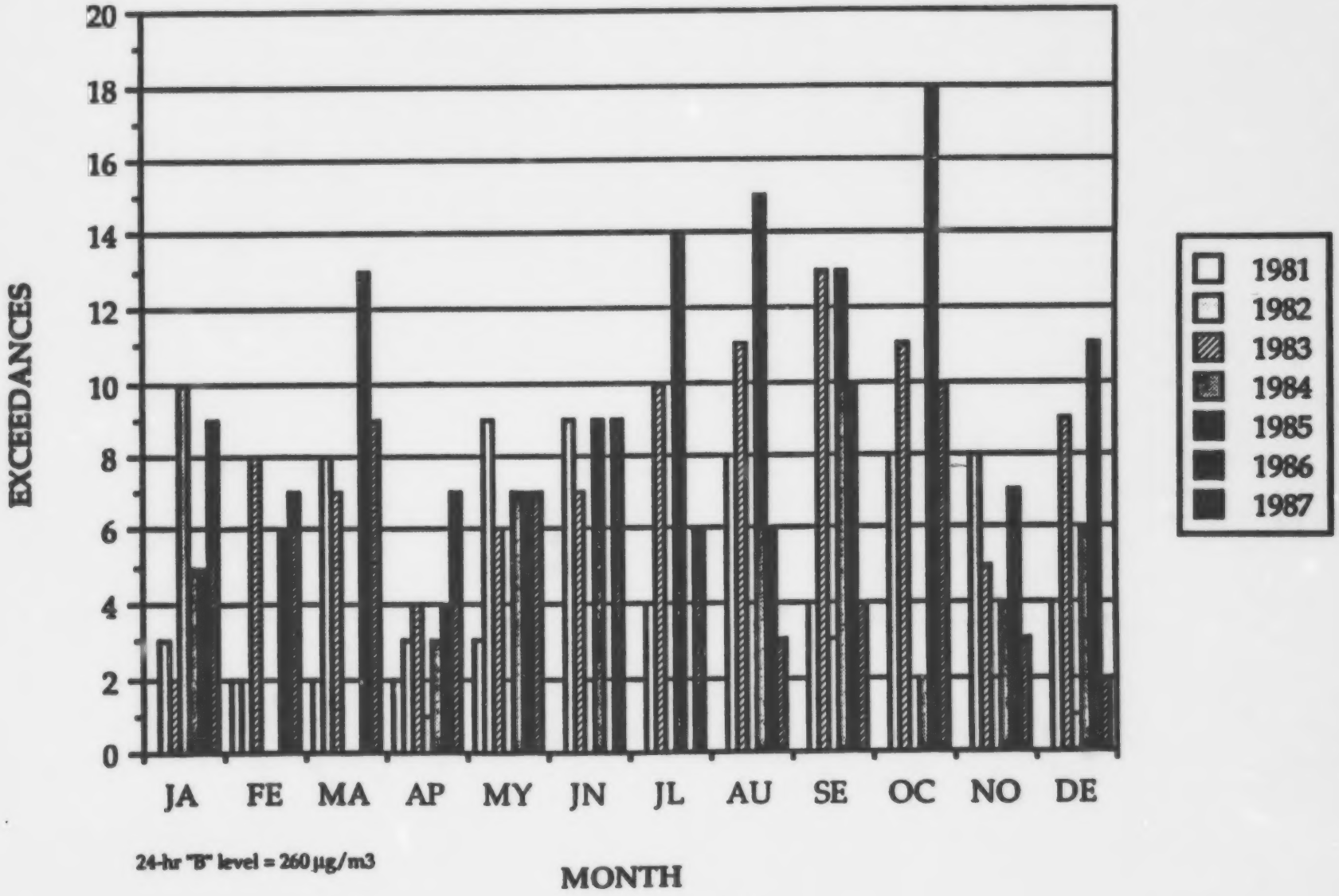
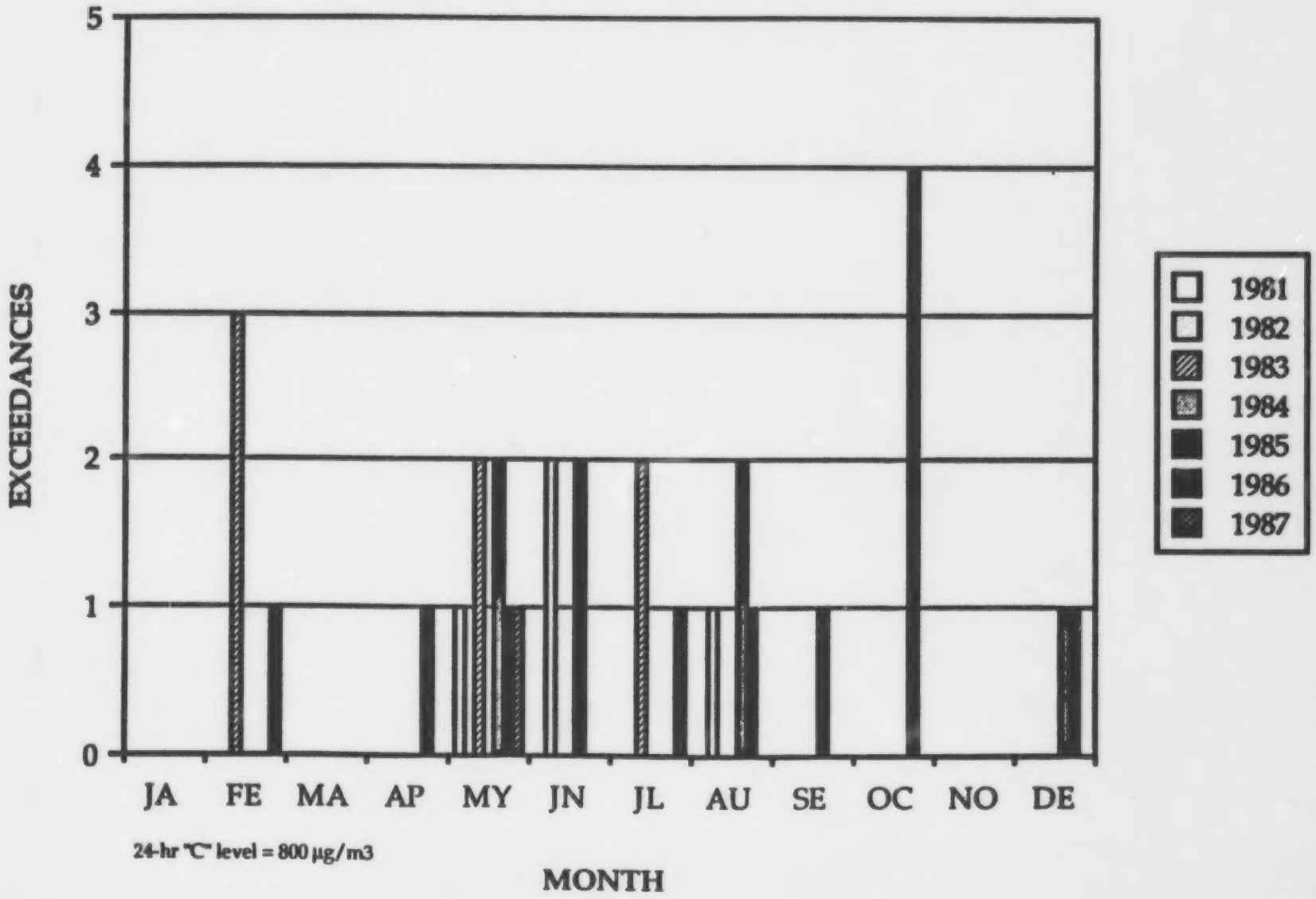


FIGURE 3.2.10 **PORT ALICE–SULPHUR DIOXIDE**
NUMBER OF 24-HOUR "C" LEVEL EXCEEDANCES–BY MONTH FOR 1981-1987



24-hr "C" level = 800 µg/m3

No temporal distribution of 24-hour "C" Level exceedances can be determined (Figure 3.2.10) as such exceedances occur sparsely.

3.3 Bio-climate

3.3.1 Climatic Moisture Stress at Port Alice, British Columbia

3.3.1.1 General

An analysis of 27 years of monthly climatological data from the Port Alice area was undertaken to identify the degree to which local coniferous vegetation may have been subjected to climatically induced moisture stresses. The season with the greatest potential climatic moisture stresses was analysed in greater detail to describe the daily trend, and magnitude, of accumulated soil moisture and climatic moisture balance.

For the purpose of this analysis, "moisture stress" refers to potential vegetation stresses induced by an accumulated potential deficiency of atmospheric moisture. There is no consideration of vegetation stresses which may result from excessive precipitation.

3.3.1.2 Methods

3.3.1.2.1 Potential Seasonal Moisture Stresses

Temperature and precipitation data for the 1958-1984 period were extracted for the climatological records from Port Alice[42]. Missing data for this climatological station were estimated by substituting the appropriate monthly data[42]

from Port Hardy Airport after the Port Hardy data were adjusted[43] to reflect the long-term relationships between the two stations.

Monthly Climatic Moisture Balance (CMB)[43] [monthly precipitation minus monthly potential evapotranspiration] was calculated for all months of all years between 1958 and 1984. Potential Evapotranspiration (PET), which is required to calculate CMB, was determined using an empirical Baier and Robertson equation[44] requiring maximum temperature, temperature range, solar radiation at the top of the atmosphere, and water vapour pressure deficit. This equation was corrected[45] to simulate a more accurate Baier and Robertson equation which uses a full range of climatological elements as input.

In order to assess the degree of Climatic Moisture Deficit[43] over a season, the Climatic Moisture Balance of consecutive months were added and a month-end running sum tabulated. When the summed CMB resulted in a Climatic Moisture Surplus, the CMB was set to zero; it is assumed that moisture surpluses are lost as run-off and do not contribute to decreasing any deficit occurring in subsequent months. Hence, Climatic Moisture Deficit (negative CMB) is summed over consecutive months and the totals are decreased by subsequent monthly surpluses until they are completely negated. When accumulated climatic moisture deficits are completely offset by surpluses both CMD and CMB are set to zero.

The maximum end-month accumulated Climatic Moisture Deficit was tabulated for each year for the period of record and is

presented in Figure 3.3.1. This maximum may occur at the end of any month although most frequently it appeared in July.

Moving averages of the annual maximum end-month accumulated CMD were computed in order to provide a trend analysis. A ten year averaging period was used to minimize the influence of the year to year variability of the data (Figure 3.3.2).

Ten year moving averages of accumulated moisture deficits were computed for a number of months and a variety of periods. Graphical presentations of these averages are found in Figures 3.3.3 through 3.3.10.

3.3.1.2.2 Extreme-Season Daily Soil Moisture and Daily Climatic Moisture Balance

In the first part of this analysis the May-August period of 1958 was found to be potentially the most stressful to coniferous vegetation due to climatological moisture deficiencies (Figure 3.3.1). This particular season was studied in greater detail to determine the daily trends of Climatic Moisture Balance and soil moisture during a period of maximum potential vegetation stress.

Daily climatological data were extracted[42] for the May to August period of 1958 for Port Alice. Daily maximum and minimum temperatures, and precipitation were assembled in a file as were daily values of top-of-the-atmosphere solar radiation.[46] This file of daily data was then input to a SAS[22] routine which computed daily potential evapotranspiration (PET), and daily Climatic Moisture Balance[43]. Potential evapotranspiration was calculated using the Baier and Robertson PET equation which required the fewest climatological elements.

Figure 3.3.1 Annual Maximum End-month Accumulated Climatic Moisture Deficit at Port Alice, B.C.

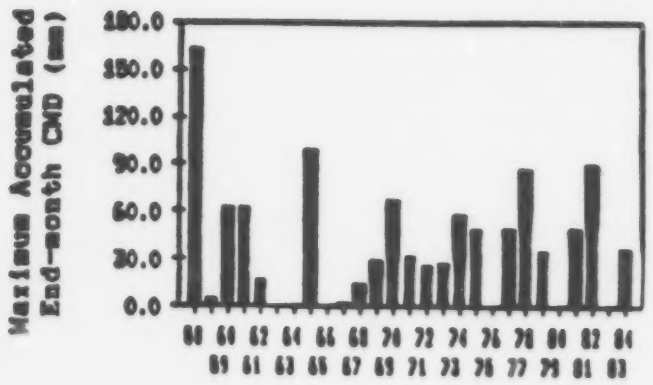


Figure 3.3.2 10-Year Moving Mean Maximum Accumulated End-month Climatic Moisture Deficit at Port Alice, B.C.

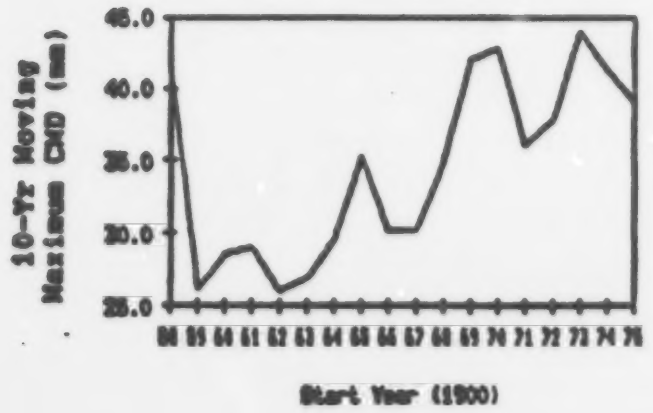


Figure 3.3.3 May-July 10-Year Moving Mean End-month Accumulated Climatic Moisture Deficit at Port Alice, B.C.

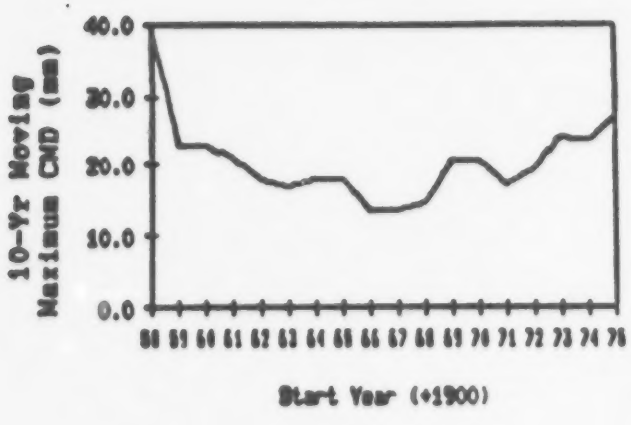


Figure 3.3.4 May-August 10-Year Moving Mean End-month Accumulated Climatic Moisture Deficit at Port Alice, B.C.

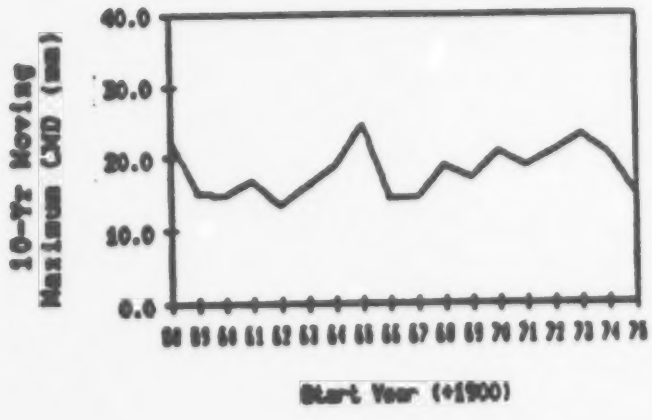


Figure 3.3.5 June 10-Year Moving Mean End-month Climatic Moisture Deficit at Port Alice, B.C.

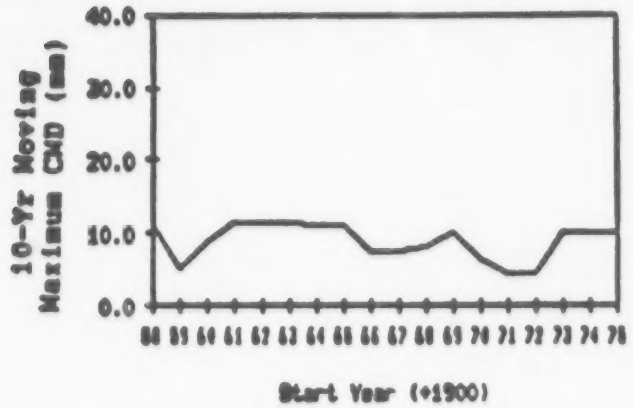


Figure 3.3.6 June-July 10-Year Moving Mean End-month Accumulated Climatic Moisture Deficit at Port Alice, B.C.

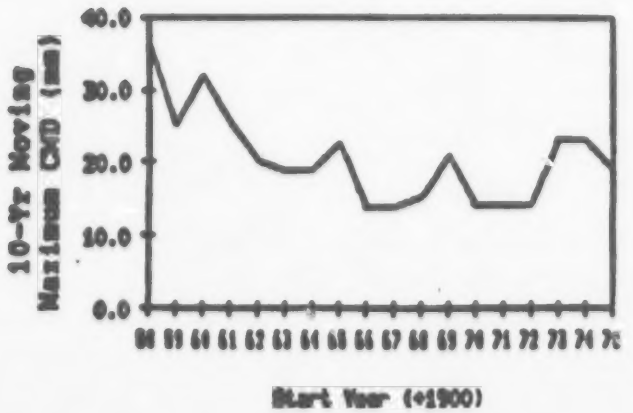


Figure 3.3.7 June-August 10-Year Moving Mean End-month Accumulated Climatic Moisture Deficit at Port Alice, B.C.

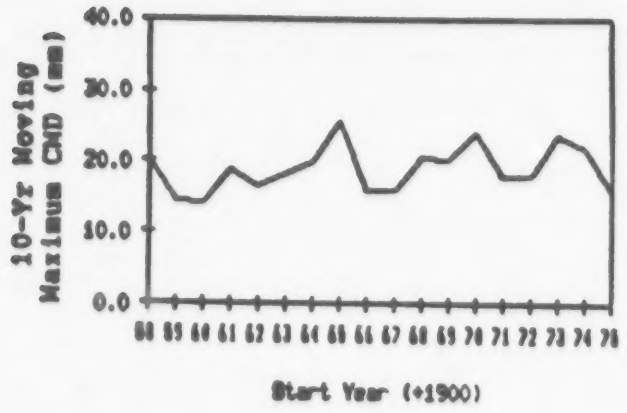


Figure 3.3.8 July 10-Year Moving Mean End-month Climatic Moisture Deficit at Port Alice, B.C.

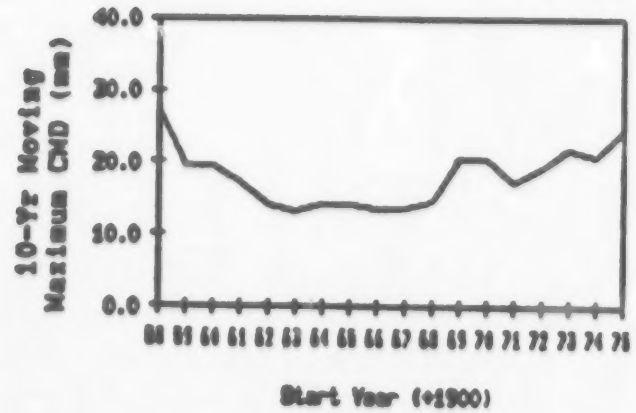


Figure 3.3.9 July-August 10-Year Moving Mean End-month Accumulated Climatic Moisture Deficit at Port Alice, B.C.

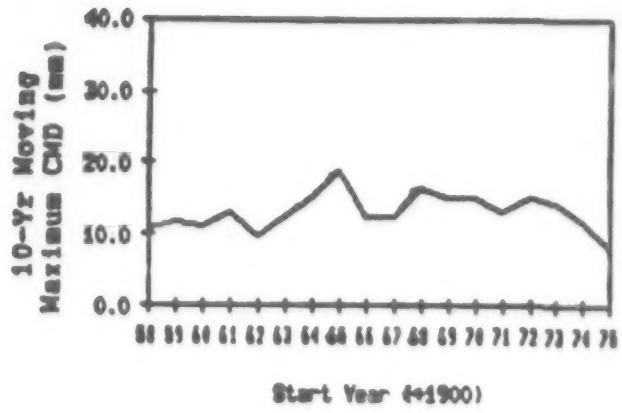
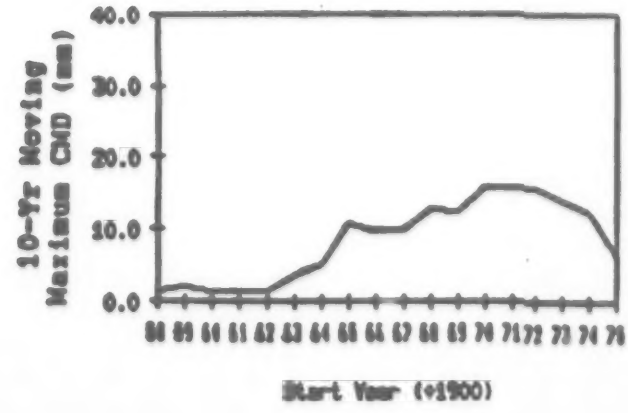


Figure 3.3.10 August 10-Year Moving Mean End-month Climatic Moisture Deficit at Port Alice, B.C.



Daily CMB calculations were accumulated starting from May 1st, 1958. Climatic moisture deficits reduced, and surpluses increased, the daily accumulated CMB. Calculations were made for all days to the end of August, 1958.

Daily CMB estimates in turn were used to calculate the amount of moisture which was available in the soil each day for the May 1st to August 31st period of 1958. Soils in the Port Alice area were assumed to have an Available Water Storage Capacity (AWSC) of 86.7 mm in the top 1 metre of profile[26]. Soils were also assumed to be fully recharged by May 1st, 1958.

The daily CMB was added to the soil moisture balance of the previous day for each day of the period studied. A day without precipitation resulted in a decrease in soil moisture; on a day when precipitation exceeded the daily PET there was a partial recharge of the soil.

3.3.1.3 Discussion

3.3.1.3.1 Potential Seasonal Moisture Stresses

Monthly Climatic Moisture Deficits have not occurred in the Port Alice area during the months of October through April. Only once did a monthly CMD occur in September; that was in 1968 with a deficit of only 5.4 mm. Similarly, monthly deficits have occurred in May only on three occasions; 1958, 1959, and 1972 when deficits of 21.7 mm, 3.6 mm, and .5 mm occurred.

With few exceptions, all CMD's occurring in the Port Alice area have occurred during the June-August period. Even so, over the period of record at Port Alice it is common for

month-end Climatic Moisture Surpluses to supersede deficits normally occurring in June, July, or August.

The maximum end-month accumulated CMD is believed to provide a reasonable indication of the severity of annual/seasonal climatic moisture stress. The annual maximum at Port Alice for the period of record is presented in Figure 3.3.1. Over this period the greatest accumulated CMD was 163 mm which occurred in 1958 as a result of a very dry May, June and July. The next greatest accumulated CMD's were in 1965, 1982, and 1978 when values of 98.6 mm, 88.3 mm, and 85.3 mm occurred.

When the 10-year moving average maximum end-month accumulated CMD is regressed with time (Figure 3.3.2) a trend towards severe CMD's since 1959 is apparent. The correlation coefficient of this regression is 0.65 and, with 16 degrees of freedom and a t-statistic of 3.51, is significant at the 99% confidence level. However, even during the most recent of the 10-year moving averages, the 10-year average maximum accumulated CMD is only 40 mm.

Ten-year moving averages of month-end CMD and accumulated month-end CMD were calculated for a variety of periods; May-July (Figure 3.3.3), May-August (Figure 3.3.4), June (Figure 3.3.5), June-July (Figure 3.3.6), June-August (Figure 3.3.7), July (Figure 3.3.8), July-August (Figure 3.3.9), and August (Figure 3.3.10). Most of these figures indicate wide fluctuations in 10-year average accumulated CMD and very few indicate any significant trends. Exceptions to this observation are found in Figures 3.3.3 (May-July), and 3.3.8 (July) where a trend of increasing CMD since 1966 is highly

significant. Since May seldom records month-end CMD's and June (Figure 3.3.5) exhibits no significant trend, the significance of the increasing May-July CMD is due primarily to the increasing July CMD.

Since the 10-year August CMD has no significant trend subsequent to 1966, it appears that the increasing CMD of July is a mid-summer phenomena which typifies neither the summer season in general nor the long-term trends in other months.

3.3.1.3.2 Extreme-Season Daily Soil Moisture and Climatic Moisture Balance

The trends in accumulated daily climatic moisture balance and daily soil moisture balance in 1958 are presented in Figure 3.3.11.

The lower half of this figure shows the accumulated Climatic Moisture Balance decreasing from a deficit of 1 mm on May 4th to an extreme deficit of greater than 300 mm on August 27th. This trend is briefly interrupted on only three occasions when rainfall more than offset the amount of moisture potentially lost due to evapotranspiration. The decrease of Climatic Moisture Balance with time, reflects the frequent occurrence of daily climatic moisture deficits. These deficits result from daily potential evapotranspiration rates which exceed daily precipitation rates and effectively serve to withdraw moisture from the soil profile.[26]

The upper half of Figure 3.3.11 shows the amount of moisture potentially available in the soil each day of the May 1 - August 31 period in 1958. The soils are considered fully

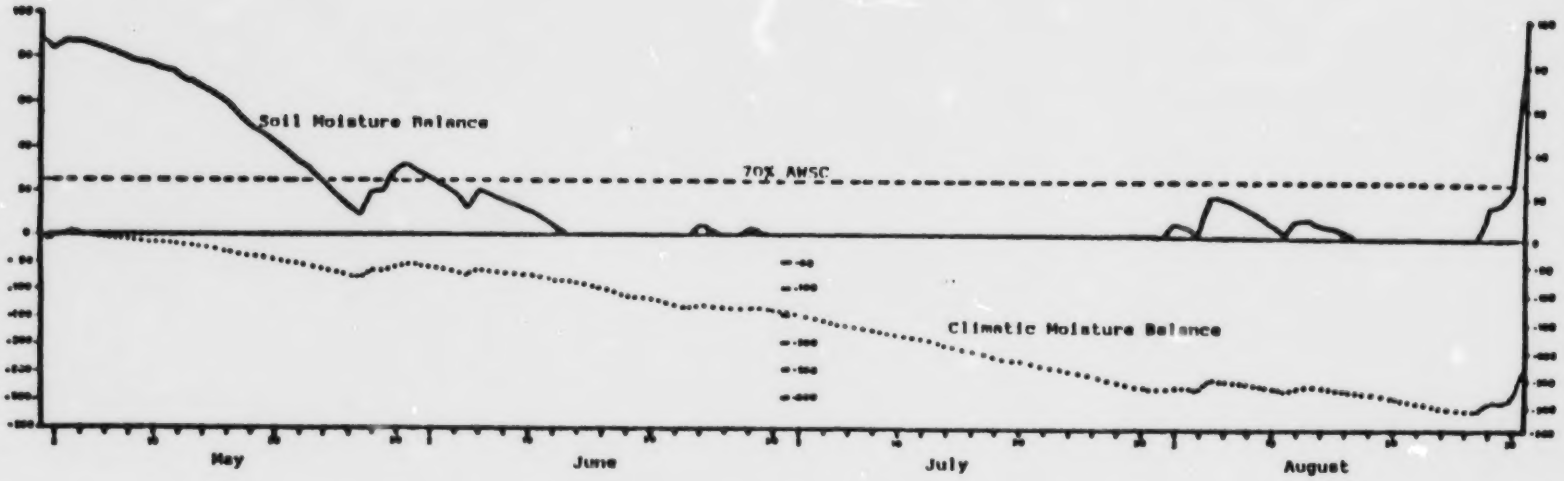


Figure 3.3.11 - Climatic Moisture Balance (dotted line) and Soil Moisture Balance (solid line) in millimetres for the period of May 1st to August 31st, 1958 at Port Alice, British Columbia. Daily precipitation contributes to recharge of the soil moisture while daily potential evapotranspiration contributes to soil moisture depletion. Port Alice soils are assumed to retain 87.6 mm of water in the top 1 metre of soil profile. The Climatic Moisture Balance in this figure indicates the net amount of moisture that would have been withdrawn from the soil if adequate quantities had been available.

recharged at the start of this period and are assumed to contain 86.7 mm of water in the top 1 metre of profile.

The 70% Available Water Storage Capacity (AWSC) level is indicated in the figure since this is the point at which vegetation ceases to draw water freely from the soil.[26] As the soil moisture decreases below this level it becomes increasingly difficult for vegetation to access the water necessary for survival. When less than 26 mm of water is retained in the soil this effect leads to an underestimate of actual soil moisture since PET calculations assume that soil moisture is evaporated at potential rates.

The Soil Moisture Balance curve in Figure 3.3.11 can be seen to respond to the Climatic Moisture Balance curve in the lower half of the same figure. Climatic moisture deficits drew moisture from the soils to May 27th when a wetter period leads to a partial soil recharge. By June 13th the soils theoretically had been depleted of moisture. This condition lasted until August 27th although a small recharge occurred in late June and 20 mm were temporarily recharged in early August. Subsequent to August 27th, late-summer weather systems brought enough moisture to the region to fully recharge the soil by September 1st.

3.3.2 Bio-climate Characteristics of the Port Alice Area for 1981 to 1985

Moisture stress, freezing temperatures, and heat energy for growth are major determinants of the time and amount of growth of vegetation critical parameters describing these factors are summarized in Table 3.3.1.

Table 3.3.1 - Bio-Climate Characteristics of the Port Alice area for the Period 1981 to 1985

YEAR																				
	1981				1982				1983				1984				1985			
PARAMETER																				
MONTH	PPT. mm	PET. mm	CMB. mm	GDD. °C	PPT. mm	PET. mm	CMB. mm	GDD. °C	PPT. mm	PET. mm	CMB. mm	GDD. °C	PPT. mm	PET. mm	CMB. mm	GDD. °C	PPT. mm	PET. mm	CMB. mm	GDD. °C
January	527	0	527	102	426	0	426	13	611	0	611	42	463	0	463	43	117	0	117	44
February	442	0	442	41	540	0	540	8	519	0	519	41	595	0	595	31	348	0	348	15
March	215	14.4	201	81	141	15.1	125	17	356	17.1	339	68	308	14.4	294	78	255	14.3	241	13
April	334	31.3	303	77	287	34.0	253	29	69	43.6	25	129	414	31.0	383	57	213	31.0	182	59
May	121	49.5	71	186	82	48.2	34	153	79	60.8	18	236	289	43.9	245	109	108	56.8	51	186
June	138	55.8	83	217	14	71.4	-58	333	129	56.4	73	249	113	57.4	56	232	40	65.5	-25	248
July	17	70.0	-53	357	38	57.8	-19	265	155	64.5	91	318	20	62.8	-43	326	14	80.2	-65	356
August	83	61.6	22	385	69	51.5	17	293	79	58.5	21	307	136	43.3	93	322	14	58.4	-45	319
September	302	32.7	270	274	142	33.0	109	245	98	32.5	65	218	220	29.1	191	223	56	36.0	20	234
October	377	0	377	133	495	0	495	154	273	0	273	136	514	0	514	134	520	0	520	128
November	627	0	627	95	341	0	341	20	595	0	595	55	403	0	403	21	125	0	125	16
December	327	0	327	22	404	0	404	9	267	0	267	3	284	0	284	4	199	0	199	26
Annual	3510	315	3195	1971	2978	311	2667	1540	3230	333	2896	1800	3760	282	3478	1580	2008	342	1666	1643
First Freeze	April 11				April 25				April 12				April 3				April 25			
Last Freeze	November 27				November 14				November 21				October 29				November 9			
# Days of Freezing	20 days				63 days				36 days				33 days				49 days			
Freeze Free Period	229				202				222				209				197			
# Days of <4°C Maximum	15 days				50 days				37 days				45 days				42 days			

Data from A.E.S., analysed by R. Marsh (Ministry of Environment)

3.4 Soil

A summary and basic descriptions of soil properties are given in Table 3.4.1. Results of laboratory analyses are presented in Table A.1.1.

All soils sampled are classified as Podzols[55] characterized by reddish brown colours and natural high acidity. Such soils are typical of high rainfall areas such as the west coast of British Columbia where leaching of base cations (e.g. calcium and magnesium) is high, and contents of residual weathering products such as iron and aluminum are relatively increased. Soils are also moderate to moderately coarse textured (ranging from loam to coarse sand), a condition itself allowing for rapid percolation and increased leaching, as well as vegetation moisture stress under any prolonged period of no precipitation.

Surficial geological materials[61], materials underlying present soils and serving as parent materials for them, were either colluvial (gravity fall or side-slope materials, typically coarse-grained and bouldery by nature), or morainal (glacial till).

3.5 Vegetation

3.5.1 Species and Observations on Sampling Sites

The characteristics of the sampling sites are summarized in Tables 3.5.1, 3.4.1. The distribution of the sample sites is presented in Figure 1.1. For each site, the tissue samples are listed, and notes on their visual appearance are presented in Table 3.5.3. Photographs of visual symptoms and

TABLE 3.4.1 - SITE INFORMATION: SOILS

SITE	SOIL SYMBOL	SOIL CLASSIFICATION[1]	HORIZON NO.	HORIZON	DEPTH (IN CM)	COLOUR[2]	TEXTURE[3]	PARENT MATERIALS[4]	GENERAL SOIL DESCRIPTION
1	PM1	O.FHP	1	LFH	10-0	5 YR 2.5/2	-	Cb = Mb/Cv[5]	Deep soils formed on materials whose composition consists of equal proportions of a colluvial blanket and a combination of till and colluvium. Underlying sedimentary rock is calcareous.
			2	Bf_1	0-20	5 YR 3/4	coarse loamy sand		
			3	Bf_2	20-40	5 YR 3/3	coarse loamy sand		
2	SB1	O.FHP	1	LFH	8-0	5YR 2.5/2	-	Mbv	A veneer of soil formed on a morainal blanket and/or veneer. Underlying rock is instrusive.
			2	Ahe	0-10	3YR 3/2	loam		
			3	Bf_1	10-40	2.5YR 3/4	coarse sandy loam		
3	PM1	O.FHP	1	LFH	15-0	5YR 2.5/2	-	Cv/Cb/Fl	Deep soils formed on colluvium ranging in thickness from a veneer to a blanket, and level fluvial deposits. Underlying sedimentary rock is calcareous.
			2	Ahe	0-13	5YR 3/4	sandy loam		
			3	Bf_1	13-28	5YR 3/3	coarse sandy loam		
4	PM1	O.FHP	1	LFH	12-0	7.5YR 2/0	-	Cf	Deep soils formed on colluvial fans. Underlying sedimentary rock is calcareous.
			2	Bf_1	0-15	5YR 3/4	sandy loam		
			3	Bf_2	15-35	5YR 3/3	coarse sandy loam		
5[6]									
6	PM8	O.FHP	1	LFH	5-0	3YR 3/2	-	Cf	Deep soils (some with cemented horizons formed on colluvial fans. Underlying sedimentary rock is calcareous.
			2	Bf_1	0-15	5YR 3/3	coarse sandy loam		
			3	Bf_2	15-35	5YR 3/2	coarse sandy loam		
7	SB5	DU.FHP	1	LFH	12-0	5 YR 2.5/2	-	Mbv//Cv[5]	Deep soils developed on materials which are dominantly morainal (varying from a blanket to a veneer) but which also have a minor component of a colluvial veneer. Soils are derived from volcanic rock.
			2	Bf_1	0-10	2.5 YR 4/6	loam		
			3	Bf_2	10-25	5 YR 4/4	loam		
8		O.FHP	1	LFH	7-0	5YR 2.5/2	-		
			2	Ae	0-20	5YR 6/2	sand		
			3	Bf_1	20-32	5YR 4/6	coarse sand		

[1] O.FHP = Orthic Ferro-Humic Podzol; DU.FHP = Duric Ferro-Humic Podzol

[2] From Munsell Colour Chart

[3] Field texture estimate

[4] Cb = Colluvial blanket; Cf = Colluvial fan; Cv = Colluvial veneer; Fl = Fluvial deposit with a level surface, generally a floodplain; Mb = Morainal blanket; Mbv = Morainal blanket/veneer. (Veneer is 10cm-1m, blanket > 1m thick)

[5] Symbols used to delineate complex units are as follows:

=	components on either side of this symbol are approximately equal	e.g Mb = R Mb and R are roughly equal
/	the component in front of the symbol is more abundant than the one that follows	Mb/R R is less than Mb
//	the component in front of the symbol is considerably more abundant than the component that follows	Mb//R R is considerably less than Mb

[6] No soil samples collected at site S5; vegetation samples only

TABLE 3.5.1 - SITE CHARACTERISTICS

SITE #	SOIL											SPECIES	COMMENTS
	DESCRIPTION	ALTITUDE	SLOPE	ASPECT	MICRO TOP	TOP MOIST	PAR. MAT	TEXTURE	DEV'T	DRAIN	SOIL ASS'N		
1 A	0.6 km N. of chip dump	300 ft	15-25%	W	smooth, straight	normal	sandstone Cv/R	gsil-gl	O.FHP	wd	Parsons Bay (PB)	western hemlock, red huckleberry, salal, bitter cherry +	15-20 yr old, very dense stand, defoliation tops of wd; few to no fungi or lichens
B	0.5 km N. of chip dump	300 ft	20-25%	NW	smooth, concave	receiving	sandstone Cb/R	co ls	O.FHP	wd	Port McNeill (PM)	western hemlock, oval-leaved blueberry, salal	mature stand, defoliation; no lichens or fungi; premature defoliation of alder and elderberry along road; cD evage
2	SW tip of Hecate Inlet, 4.6 km from mill	0 ft	50%	S-SE	smooth, straight	normal	Mbv	l-co sl	O.FHP	wd-cd	Sprise (SS)	western hemlock, coast Douglas-fir, red huckleberry, epiphytic mosses and lichens	older needles, more chlorotic, fallen tree with witch's brooms; no symptoms direct line of sight to mill
3	Above mill to Victoria Lake Rd.; 2 km from mill	500 ft	30%	W	smooth, convex	shedding	Cv/Cb/Fl	sl-co sl	O.FHP	wd	Port McNeill (PM)	western hemlock, American red elder, salal, oval-leaved blueberry, western hemlock regen, deerfern, swordfern, shieldfern, red alder +	heavy Phellinus infection on evage; wd dead tops and witch's brooms; defoliation throughout; no mosses or lichens on ground; some moss on evage; premature leaf drop
4	At monitoring station N. of mill; lower bench above Inlet; approx. 0.3 km from mill	50 ft	10-20%	W	smooth, concave	receiving seepage	Mb-Cf/Mb	sl-co sl	O.FHP	mwd	Williams Lake (WL)	red alder, western hemlock, English ivy, black raspberry, American red elder, bitter cherry, common periwinkle, deerfern, buttercup, thistle, dock, cat's ear, orchard grass	classic acute symptoms - interveinal necrosis on rAl and Rubu ura. Lichen desert defoliation; no decay factors; typical Cx6-enf ecosystem

TABLE 3.5.1 - SITE CHARACTERISTICS (Continued)

SITE #	SOIL											SPECIES	COMMENTS
	DESCRIPTION	ALTITUDE	SLOPE	ASPECT	MICRO TOP	TOP MOIST	PAR. MAT	TEXTURE	DEV'T	DRAIN	SOIL ASS'N		
5 A	0.5 km from Jeune Ldg. Rd.; approx. 0.4 km from mill	75 ft	0-5%	W	irregular	normal	limestone R-Cv/R		disturbed roadbank folisol	wd	Hansen (HN)	advanced regen on roadcut; red alder below road	dead tip on cD; chlorotic tips on cD; tipburned wC
B	0.6 km on Jeune Ldg. Rd. above Hwy. yard; approx. 6.2 km from mill	100 ft	30%	W	straight, bench slope	normal	limestone Cv/R			wd	Hesquiat (HQ)	western hemlock, coast Douglas-fir veterans, western hemlock regen, salal	many dead tops in cD and witch's broom in wH
6	Port Alice, Humble Beach next to Legion Hall; approx. 5 km from mill	50 ft	0-3%	W	hummocky	receiving	Cf	co l/ co sl	O.FHP	wd-md	Port McNeill (PM)	red alder, western hemlock, western red cedar, oval-leaved blueberry, salmonberry, swordfern, American red alder, salal	salal with browning; elderberry leaves black and damaged possibly from frost; swordfern with some marginal injury
7	Near Port Hardy above MP station; approx. 25 km N. of Port Alice mill	100 ft	5%	N-NW	convex	normal	Mbv/Cv	l	Du.FHP	wd	Sarita (SR)	western hemlock regen, western red cedar regen, amabilis fir regen, western yew, shorepine, deerfern, salal, salmonberry, rusty Pacific menziesia	10-15 year old logging; dense salal, patchy dense advanced regen
8	Tsitika; approx. 65 km east of Port Alice mill	950 ft	10-30%	W	straight, irregular	receiving seepage	Cf/Mb granitic origin	s-co s	O.FHP	md-sp		western hemlock, western red cedar, amabilis fir, trees and regeneration; deerfern, northern twinflower, Canadian bunchberry, oval-leaved blueberry, layered moss, pyxie cups	mature stand just above recent logging; well away from sources of air pollution (clean air control)
9	Humble Beach, above townsite	600 ft	10%	W	convex-straight irregular	receiving	Cf	?	various	wd md	Port McNeill (PM)	as site 6. More disturbed	Active fan and a dike. Many pioneer species. Nutrient stress and SO_2

TABLE 3.5.2
SAMPLE CHARACTERISTICS AND OBSERVATIONS (1986)

Sample # - 1986	Site	Description	Appearance
1	4	Salmonberry foliage, symptoms	some interveinal necrosis on mature and immature leaves; 18 of 37 trifoliate-leaves showed symptoms; and leaves are distinctly smaller
2	4	Salmonberry foliage, no visible symptoms	
3	4	Salmonberry stems, 1985, yr 0	
4	4	Salmonberry stems, 1984, yr 1	
5	1	Sitka spruce, defoliation, yr 0	advanced regen, densely enclosed by western hemlock regen; some branches defoliated at yr 1 and yr 2; brown tips and banding on
6	1	Sitka spruce, defoliation, yr 1	leaves of some yr 1 and yr 2 of some branches; chlorotic yellow-green yr 2 foliage; some dead bands at bottom half of leaves,
7	1	Sitka spruce, defoliation, yr 2	nearly all brown-tipped on yellow (chlorotic) field; no current
8	1	Sitka spruce, defoliation, yr 3	year growth on defoliated branches; some auxiliary dwarf shoots on
9	1	Sitka spruce, defoliation, yr 4 and older	defoliated branches
10	1	Sitka spruce, no symptoms, yr 0	site as above, no visible symptoms on these twigs from same tree
11	1	Sitka spruce, no symptoms, yr 1	
12	1	Sitka spruce, no symptoms, yr 2	
13	1	Sitka spruce, no symptoms, yr 3	
14	9	Salmonberry, foliage, visible symptoms	visible injury from light, of "coppery" flecks, to more intensive injury of interveinal areas of "shiny coppery" necrotic areas; most severe injury of marbled "green-coppery" near veins; all stages of leaf development involved; prior to turning "coppery necrotic" a dull dark-green "soaked" appearance is evident
15	9	Western hemlock, regen, yr 0	yr 1 foliage with dead tips or constricting chlorotic pattern; some with lateral or central dead (brown) spots
16	9	Western hemlock, regen, yr 1	
17	9	Western hemlock, regen, yr 2 and older	leaves heavily infested with red aphid galls; marginal and
18	4	Maple foliage, exposed free-growing tree	interveinal flecks of yellowish-white necrotic areas. Emerging leaves red in color
19	9	Red alder, foliage, free-growing shrub	juvenile foliage bronzed and some dark-brown necrotic; mature foliage not affected
20	9	Coast Douglas-fir, in canopy, yr 0	long, slender branches of dark dense stand, few with current year
21	9	Coast Douglas-fir, in canopy, yr 1	growth; few yellow-brown spots and bands on yr 1 and yr 2; year 3
22	9	Coast Douglas-fir, in canopy, yr 2	- some defoliation, possibly insect browsing; yr 5 and older
23	9	Coast Douglas-fir, in canopy, yr 3	foliage - some apical and basal chlorosis and orange/green/orange/
24	9	Coast Douglas-fir, in canopy, yr 4	yellow/light-green, normal green banding
25	9	Coast Douglas-fir, in canopy, yr 5 and older	
26	6	Unium insigne moss, forest floor	many white necrotic spots, outlined by a ring of dark-brown to black dying or dead cells; dark rings may remain faintly visible as brown rings; clear centres may form "holes" red-brown-tipped branchlets and tips
27	9	Western red cedar, in canopy	

Sample #-1985	Site	Description	Appearance
1	1A	Western hemlock, 1985 foliage & stems	light green, some flecking of light rusty spots
2	1A	Western hemlock, 1984 foliage & stems	medium to light green foliage, sparse, some flecks
3	1A	Sedge species roots & crowns	fibrous roots, few short rhizomes, crowns red
4	1A	Sedge species dead straw	yellow grey to blackish brown
5	1A	Sedge species live foliage	mostly at least 1/3 of tip dead, medium green
6	1A	Red huckleberry foliage & stems	foliage senescing, not chlorotic
7	1A	Wood-rush live & dead foliage, culm & fruit	light to medium green culm, straw
8	1A	Wood-rush roots & crowns	primarily fibrous roots
9	B	Western white pine, 1985 foliage & stems	healthy medium green foliage
10	B	Western white pine, 1984 foliage & stems	healthy medium green foliage
11	B	Amabilis fir, year 0	healthy light green foliage, yellow-straw colored stems
12	B	Amabilis fir, year 1	dark green, clean foliage; stems greenish-brown
13	B	Amabilis fir, year 2	dark green to black tarnished foliage; stems brownish green
14	B	Amabilis fir, year 3	dark green tarnished foliage, stems black on green
15	B	Amabilis fir, year 4 and up	dark green tarnished foliage, stems black on green
16	B	Western hemlock, understory, year 0	medium green/d. yellow stems, healthy
17	B	Western hemlock, understory, year 1	foliage medium green, stems green, healthy
18	B	Western hemlock, understory, year 2	foliage medium green, stems greyish
19	B	Western hemlock, upper canopy, cones	only light brown cones, bearing many seeds
20	B	Western hemlock, upper canopy, fruit bearing branches, 1 - 6 years	branches stubby, needles somewhat fascicled medium-yellowish green, twigs black and "dirty"
21	B	Layered moss, ground cover	up to 6 layers, 3 - 4 green; decaying mat. removed
22	B	Hylocomium moss, epiphyte	very fine tangle of branches at 2 m on trunk of a F.
23	B	Rhytidiadelphus moss, epiphyte	on trunk and branches of AF, at app. 2 m height
24	1B	Western hemlock adv. regen, injured tops, year 0	some bare, dried-up tips, 20-30% defoliation and yellow flecking
25	1B	Western hemlock adv. regen, injured tops, year 1	severe defoliation (60-75%), yellow flecks/bands common
26	1B	Western hemlock adv. regen, injured tops, year 2	near complete defoliation
27	1B	Western hemlock adv. regen, in canopy, year 0	appears reasonably healthy; relatively many non-flushing year 1 dwarf shoots; occasional tip kill and few yellowish banding or flecks; some 40% defoliation
28	1B	Western hemlock adv. regen, in canopy, year 1	
29	1B	Western hemlock adv. regen, in canopy, year 2	
30	1B	Western hemlock adv. regen, in canopy, year 3	
31	1B	Red huckleberry leaves and senesc. leaves	leaves badly discolored and falling from normal fall senescence if injury present, not distinguishable from aging!
32	1B	Salal leaves	some groups of leaves with tip and marginal necrosis, and interveinal chlorosis; others look fine (brute?)
33	1B	Salal green stems	green stems, no distinguishing marks/colors
34	2	Western hemlock understory, year 1	no evidence of year 0 growth; few dead tips
35	2	Western hemlock understory, year 2	no comments
36	2	Western hemlock, fallen, in-crown mature foliage, year 0	fallen tree; lichen in crown, some dead tips and defoliation; suspect cause other than SO,
37	2	Western hemlock, fallen, in-crown mature foliage, year 1	may be more than usual "dwarf" shoots, but normal
38	2	Western hemlock, fallen, in-crown mature foliage, year 2	some dead twigs
39	2	Western hemlock, fallen, in-crown mature foliage, year 3+	no needles
40	2	Western hemlock, top crown, year 0-1	little year 0 growth, many axis chlorosis on 1 and 2 year old slight defoliation, tip die-back, some slight blemishes, many "stubby" near dwarf shoots
41	2	Western hemlock, top crown, sample: year 2	as 40
42	2	Alectoria lichen, fallen tree, in-crown	yellow-green
43	2	Parmelia lichen, fallen tree, in-crown	difficult to separate from bark; small samples!
44	4	Scouler's willow, leaves	leaves naturally senescent (fall!), marginal necrosis at lowest points (varies with leaf position), yellow interveinal chlorosis, some orange-brown flecking, mainly interveinal
45	4	Scouler's willow, twigs, year 0	bole thick, twigs red
46	4	Buttercup, foliage	severe marginal and tip necrosis, black, dark green, native white spots
47	4	Orchard grass, above ground (roots removed)	many dead tips, white flecks on dead tips
48	4	Red alder, leaves	classical symptoms; chlorosis, necrosis-intercalary and terminal; red and yellow
49	3	Western hemlock, understory, in-crown foliage, year 1	moderate defoliation; some foliage dried, pale brown-green; some orange banding mid-leaf and base
50	3	Western hemlock, understory, in-crown foliage, year 2	severe defoliation and red/orange mid-needle marginal colors
51	3	Western hemlock, understory, in-crown foliage, year 3+	moderate-severe defoliation; foliage dark, generally bronzed particularly along the mid-vein
52	3	Western hemlock, top foliage from cut tree, year 0	light yellow-green stress flushing, some dead defoliated tips
53	3	Western hemlock, top foliage from cut tree, year 1	dark green, severe defoliation, red banding and flecking, bronzing
54	3	Western hemlock, top foliage from cut tree, year 2	severe defoliation, banding, bronzing
55	3	Western hemlock, top foliage from cut tree, year 3+	devoid of leaves, tip and central vein bronzing
56	3	Dicranum moss, on stump facing mill	only surface green and dead shoots, some lower dead shoots
57	3	Swordfern, understory fronds damage	orange necrosis in central sections of pinnae
58	3	Salal, understory foliage damage	terminal and lattteral marginal orange-brown necrosis
59	3	Deerfern, fronds understory damage	terminal die-back on some upper-pinnae, laminar bronzing between margins and veins
60	3	Red huckleberry, stems and leaves	advanced fall senescens undistinguishable from injury, green leaves have clear "holes and spots", could be injury
61	4	Black raspberry, foliage damaged/injured	marginal purple coloring; interveinal bronzing and coloring, yellow-red marginal necrosis interveinal
62	4	Common periwinkle, leaves	appears healthy, some slightly lighter coloring along veins, color appears lighter and yellower than normal
63	4	Salal, leaves and stems	orange necrosis, chlorotic yellowing, tip and margin necrosis
64	4	Swordfern, fronds damaged	severe tip and marginal necrosis; brown and yellow, sharp margin with remaining green; some soil on some fronds
65	5A	Western hemlock, top of canopy, year 0	yellow-green juvenile shoots with sporadic spots, dead tips or severed tips
66	5A	Western hemlock, top of canopy, year 1	dark green, anture; 2 cones (removed!) fertile, sporadic flecks
67	5A	Western hemlock, top of canopy, year 2	dark green, some brown areas with lesions through leaf thickness
68	5A	Western hemlock, top of canopy, year 3+	frequent brown flecking areas, mostly underneath leaf, dark green
69	5A	Western hemlock, lower canopy, understory, year 0	white flecks on upper surface near leaf base
70	5A	Western hemlock, lower canopy, understory, year 1	common white flecks (separating epidermis) on upper surfaces of leaves, some damaged growth tips, some defoliation in some tips (unidentified causes)
71	5A	Western hemlock, lower canopy understory, year 2	abundant white flecking, pink glassy-bead fungus on leaves, some browning at bottom of a few leaves
72	5A	Western hemlock, lower canopy understory, year 3	grey-green surface, from app. 40-60% flecking, starting to brown-yellow near some leaf bases; some needle tips dead and brown
73	5A	Western hemlock, lower canopy understory, year 4	as above; some browning more pronounced over whole upper surface; some appearing as cross-banding
74	5A	Western hemlock, lower canopy understory, year 5+	as above; all white, somewhat cream to brown tinged
75	5B	Coast Douglas-fir, advanced regen, year 0	yellow-green flecked chlorotic, many dead tipped needles, some defoliation
76	5B	Coast Douglas-fir, advanced regen, year 1	defoliation, darker green with chlorotic flecks and tips
77	5B	Coast Douglas-fir, advanced regen, year 2	dark green with chlorotic flecks, many dead tipped needles, some defoliation
78	5B	Coast Douglas-fir, advanced regen, year 3 + 4	some mid-leaf banding, moderate-light chlorosis, lead tip damage
79	5B	Western red cedar, advanced regen, year 0	dead tips, brown-bronzing throughout upper surface; pronounced to tips
80	5B	Western red cedar, advanced regen, year 1	some dead tips; bronzing on upper surface
81	5B	Western red cedar, advanced regen, year 2	50-60% of tips dead; browning-bronzing on upper surfaces
82	5B	Coast Douglas-fir, adv. regen, free growing, year 0	flaccid, brown-tipped needles, yellow-green chlorotic, heavy needle drop
83	5B	Coast Douglas-fir, adv. regen, free growing, year 1	severe needle drop, looks dried out, some tip burn
84	6	Western hemlock, in-crown, understory, year 0	some dead tips and flecked foliage, 1 yellow-green
85	6	Western hemlock, in-crown, understory, year 1	dark green, little occasional defoliation
86	6	Western hemlock, in-crown, understory, year 2	[illegible] symptoms
87	6	Western hemlock, in-crown, understory, year 3+	more sparsely foliated, some defoliation, possible symptom
88	6	Swordfern, fronds, visibly injured	many dead pinnae, others with interveinal browning and necrosis, 60-80%
89	6	Swordfern, fronds, little or no visible injury	one tip has a group of dead pinnae
90	6	Red huckleberry, stems and leaves	advanced fall senescence unlike any visible symptom
91	6	American red elder, leaflets	blackened from freezer storage, visible injury marked if present
92	6	Red alder, leaves	lacerated and classic necrosis patterns on leaves; no fall senescence
93	6	Salal, stems and leaves	interveinal chlorosis and browning, pronounced on back of leaf, some marginal and tip necrosis, growth tips of stems dead
94	7	Amabilis fir, advanced regen, year 0	healthy medium-green (juvenile)
95	7	Amabilis fir, advanced regen, year 1	dark-yellowish green towards the tips of needles
96	7	Amabilis fir, advanced regen, year 2	dark-yellowish green towards the tips of needles
97	7	Amabilis fir, advanced regen, year 3+	dark-yellowish green towards the tips of needles
98	8	Coast Douglas-fir adv. regen in logged area, year 0	few chlorotic spots scattered throughout foliage
99	8	Coast Douglas-fir adv. regen in logged area, year 3	needles frequently injured, dark green-brown areas possibly from drying out
100	8	Coast Douglas-fir adv. regen in logged area, year 2	most needles with chlorotic spots and/or severed tips, apparent mechanical damage
101	8	Coast Douglas-fir adv. regen in logged area, year 1	healthy dark-green, free from chlorotic and "eaten" leaves
102	7	Western hemlock, adv. regen, year 0	healthy
103	7	Western hemlock, adv. regen, year 3+	healthy
104	7	Western hemlock, adv. regen, year 1	healthy
105	7	Western hemlock, adv. regen, year 2	healthy

the appearance of the samples are presented in Plates A.3.6 to A.3.37.

On June 19, 1986, a number of symptoms were observed on garden vegetation in the Rumble Beach townsite. The symptoms ranged from dead tips on branches, through sparse crown foliage and small leaves, to classical interveinal chlorosis and necrosis. Species affected included Scots broom, birch, weeping willow, maple cultivar, Lombardy poplar, black cottonwood, Japanese cherry, spirea cultivar, apple, and others.

"Foliage: Stem" dry weight ratios are presented in Table 3.5.4. Each site is subjectively rated for sulphur dioxide impacts. For each site, the dry weight of foliage is compared with the dry weight of the stems that supported the foliage. Each ratio was determined for a year of growth. Calculations were completed for western hemlock, amabilis fir, western white pine and coast Douglas-fir. At year 0 (current years growth) for western hemlock the ratio foliage:stem ranged from 4.7 to 9.0 for healthy branches, to 0.0 to 5.8 for visibly injured trees. The ratios declined with age. For amabilis fir, western white pine and coast Douglas-fir, the ratios tended to be somewhat lower, and with similar relationship over age. The ratios varied with position in the canopy, with open grown foliage being more abundant in healthy forests but with greater defoliation impacts in areas of injurious levels of sulphur dioxide.

3.5.2 Tissue Sulphur Content

Samples of the above foliage as well as samples of a number of selected shrubs and understory species were analysed for

TABLE 3.5.4
Foliage:Stem Ratios for Various-Aged Twigs of Western Hemlock, Coast Douglas-Fir, Amabilis Fir and Western White Pine by Canopy Position

SITE	IMPACT	AGE	SPECIES							
			wH		amF		wP		cD	
			TOP	IN CAN.	TOP	IN CAN.	TOP	IN CAN.	TOP	IN CAN.
1A	H	0		1.309						
		1		0.098						
		2								
		3								
1B	H	0	2.698*	5.818						
		1	0.769*	3.028*						
		2	0.006*	1.355*						
		3		0.238*						
2	vL	0	4.507	6.509+						
		1		2.875+						
				3.141+						
		2	1.264	0.712+						
				0.286+						
		3		0.014+						
3	M-H	0	2.789*							
		1	0.770*	3.899*						
		2	0.083*	0.525						
		3	0.022*	0.309						
4	vH	0								
		1								
		2								
		3								
5A	L	0	9.008	7.423						
		1	6.555	2.912+						
		2	1.604	2.995						
		3	1.361	1.343						
		4		0.903						
		5		0.150						
5B	L	0							7.302	
		1							4.390	
									0.767*	
		2							1.655*	
		3							2.069	
									1.988	
6	M	0		5.477*						
		1		2.220						
		2		0.968						
		3		0.513						
8	M	0		4.701		4.015	3.720		3.715	
		1		2.922		2.924	1.897		1.905	
		2		1.483		2.619			0.651	
		3				2.899			0.184	
		4	1.528	(1.528)		1.592				
7	M	0		5.392	3.733					
		1		3.498	2.646					
		2		2.006	2.362					
		3		0.369	2.380					

* Branches visibly injured
\+ Injury/Damage from unknown causes

Note: Initial response is formation of many dwarf shoots. This may somewhat counteract the effects of defoliation (cD in 5B).

sulphur content[29]. These data are presented in Table 3.5.5. The samples are stratified by sampling site, species, and position in relation to the vegetation canopy. An analysis of the tap water used to wash the samples, and that of paper bags used for storage of the tissues while drying and during transport to the lab is included. The higher sulphur content of 1.14% (by weight) was found in 2 year old foliage of exposed (upper canopy) western hemlock. Evergreen broadleaf species, periwinkle and salal, and older conifer foliage also tended to have high sulphur content values of between 0.80% and 1.00%.

3.5.3 Other Possible Causes of Injury or Damage

3.5.3.1 Soil Moisture Deficit

Available water storage capacity (AWSC) for a sandy loam (sl) soil is approximately 0.125 cm/cm. Adjustment for a coarse component in the soil of 30% (co sl) projects an AWSC 0.0875 cm/cm. For a typical soil depth of 1 m an AWSC of 87.5 mm may be projected.[26] For shallower soils this capacity will be lower. Soil depths greater than 1 m extend beyond the rooting zone and are not expected to contribute significantly to moisture available to plants. Soils subject to seepage, high water tables etc. may have a continuous supply of moisture and are not subject to desiccation from a climatic moisture deficit.

A moisture stress of approximately -15 to -20 bars may remove up to 40% of the moisture or 61.25 mm. A stress of -15 bars represents a limit for tree-growth, and is the wilting point for many crop plants. Osmotic potential of plant cells approximates -30 bars[26]. At soil moisture osmotic potentials

TABLE 3.5.5
Percent Sulphur Content of Leaf and Stem Tissue of Selected Species by Site, Age and Canopy-Position+
(B.C. Min. of Agriculture and Food: Soil, Feed, Tissue, and Water Analysis Lab., Kelowna)

85 Samples

Lab No.	Site	Species	Age	Percent Sulphur	Pos	Lab No.	Site	Species	Age	% Sulphur	Pos
1	1A	wH	<3 mos	0.57	I	54	3	wH	2 yrs	0.83	U
2	1A	wH	1 yr	0.84	I	55	3	wH	>3 yrs	0.79	U
3	1A	Sedge roots	N/A	0.11	G	56	3	Dicranam fususcens	N/A	0.22	E
4	1A	Sedge straw	N/A	0.07	G	57	3	Polystichum munitum	N/A	0.43	G
5	1A	Sedge foliage	N/A	0.30	G	58	3	Gaultheria shallon foliage	N/A	0.66	G
6	1A	Vacc. paru. foliage and stem	N/A	0.49	G	59	3	Blechnum spicant	N/A	0.48	G
7	1A	Luzula paru. foliage	N/A	0.13	G	60	3	Vacc. parv. foliage and stems	N/A	0.49	G
8	1A	Luzula paru. roots	N/A	0.09	G						
9	8	wP	<3 mos	0.13	U	61	4	Rubus leucodermis foliage	<3 mos	0.61	G
10	8	wP	1 yr	0.12	U						
11	8	amF	<3 mos	0.07	I	62	4	Vinca minor foliage	N/A	0.99	G
12	8	amF	1 yr	0.07	I	63	4	Gaultheria shallon foliage and stems	N/A	0.82	G
13	8	amF	2 yrs	0.08	I						
14	8	amF	3 yrs	0.09	I	64	4	Polystichum munitum	N/A	0.37	G
15	8	amF	>4 yrs	0.08	I	65	5A	wH	<3 mos	0.16	U
16	8	wH	<3 mos	0.10	I	66	5A	wH	1 yr	0.30	U
17	8	wH	1 yr	0.10	I	67	5A	wH	2 yrs	0.39	U
18	8	wH	2 yrs	0.11	I	68	5A	wH	>3 yrs	0.40	U
19	8	wH cones	N/A	0.13	U	69	5A	wH	<3 mos	0.11	I
20	8	wH fruit-bearing twigs		0.07	U	70	5A	wH	1 yr	0.19	I
						71	5A	wH	2 yrs	0.27	I
21	8	Hylocomium splendens		0.04	G	72	5A	wH	3 yrs	0.32	I
22	8	Hypnum cireinatum		0.06	E	73	5A	wH	4 yrs	0.41	I
23	8	Rhytidiadelphus loreus		0.04	E	74	5A	wH	>5 yrs	0.46	I
						75	5B	cD	<3 mos	0.14	U
24	1B	wH	<3 mos	0.72	U	76	5B	cD	1 yr	0.18	U
25	1B	wH	1 yr	0.91	U	77	5B	cD	2 yrs	0.17	U
26	1B	wH	2 yrs	1.14	U	78	5B	cD	3 & 4 yrs	0.19	U
27	1B	wH	<3 mos	0.47	I	79	5B	wC	<3 mos	0.17	U
28	1B	wH	1 yr	0.54	I	80	5B	wc	1 yr	0.14	U
29	1B	wH	2 yrs	0.82	I	81	5B	wc	2 yrs	0.11	U
30	1B	wH	3 yrs	0.95	I	82	5B	cD	<3 mos	0.17	U
31	1B	Vacc. Paru. foliage and stem	N/A	0.67	G	83	5B	cD	1 yr	0.38	U
						84	6	wH	<3 mos	0.17	I
32	1B	Gaultheria shallon leaves	N/A	0.67	G	85	6	wH	1 yr	0.31	I
						86	6	wH	2 yrs	0.49	I
33	1B	Gaultheria shallon stems	N/A	0.12	G	87	6	wH	>3 yrs	0.55	I
						88	6	Polystichum munitum	N/A	0.45	G
34	2	wH	1 yr	0.29	I	89	6	Polystichum munitum foliage	N/A	0.32	G
35	2	wH	2 yrs	0.32	I						
36	2	wH	<3 mos	0.13	I	90	6	Vacc. paru. foliage	N/A	0.35	G
37	2	wH	1 yr	0.25	I	91	6	Sambucus racemosa foliage	N/A <3 mos	0.45	I
38	2	wH	2 yrs	0.29	I						
39	2	wH	>3 yrs	0.32	I	92	6	Alnus rubra foliage	N/A	0.27	I
40	2	wH	<1 yr	0.21	U	93	6	Gaultheria shallon foliage	N/A	0.32	G
41	2	wH	2 yrs	0.30	U						
42	2	Alectoria sarment	N/A	0.06	E	94	7	amF	<3 mos	0.06	U
43	2	Parmelia sulcata	N/A	0.09	E	95	7	amF	1 yr	0.06	U
44	4	Salix scouleriana foliage	N/A	0.91	I	96	7	amF	2 yrs	0.06	U
						97	7	amF	>3 yrs	0.07	U
45	4	Salix scouleriana stem	<3 mos	0.14	I	98	8	cD	<3 mos	0.14	U
						99	8	cD	3 yrs	0.20	U
46	4	Ranunculus repens foliage	<3 mos	0.79	G	100	8	cD	2 yrs	0.16	U
						101	8	cD	1 yr	0.13	U
47	4	Dactylus glomerata foliage	<3 mos	0.34	G	102	7	wH	<3 mos	0.08	U
						103	7	wH	>3 yrs	0.11	U
48	4	Alnus rubra foliage	<3 mos	0.52	I	104	7	wH	1 yr	0.09	U
49	3	wH	1 yr	0.70	I	105	7	wH	2 yrs	0.12	U
50	3	wH	2 yrs	0.66	I	106	8	wH cones	N/A	0.02	U
51	3	wH	>3 yrs	0.78	I	107	N/A	paper bag	N/A	0.10	
52	3	wH	<3 mos	0.43	U		N/A	tapwater	N/A	0.0005*	
53	3	wH	1 yr	0.70	U						

86 Samples

1	4	Salmonberry, foliage	<2 mos	0.35	G	15	9	wH, foliage	<2 mos	0.14	U
2	4	Salmonberry, foliage	<2 mos	0.31	G	16	9	wH, foliage	1 yr	0.32	U
3	4	Salmonberry, stems	<2 mos	0.07	G	17	9	wH, foliage	>2 yr	0.33	U
4	4	Salmonberry, stems	1 yr	0.07	G	18	4	Maple, foliage	<2 mos	0.45	U
5	1	Ss, foliage	<2 mos	0.18	I	19	9	rAl, foliage	<2 mos	0.16	U
6	1	Ss, foliage	1 yr	0.45	I	20	9	cD, foliage	<2 mos	N	I
7		Ss, foliage	2 yr	0.39	I	21	9	cD, foliage	1 yr	0.11	I
8	1	Ss, foliage	3 yr	0.44	I	22	9	cD, foliage	2 yr	0.31	I
9	1	Ss, foliage	>4 yr	N	I	23	9	cD, foliage	3 yr	0.21	I
10	1	Ss, foliage	<2 mos	0.07	I	24	9	cD, foliage	4 yr	0.25	I
11	1	Ss, foliage	1 yr	0.47	I	25	9	cD, foliage	>5 yr	0.64	I
12	1	Ss, foliage	2 yr	0.40	I	26	6	Mnium insignemoss	-	0.18	G
13	1	Ss, foliage	3 yr	0.44	I	27	9	wC, branches	>2 mos	0.13	I
14	9	Salmonberry, foliage	<2 mos	0.43	G						

+ I = in canopy, U = upper canopy, G = groundcover/forest floor, E = epiphytic
* From Ministry of Environment, Environmental Laboratory

more negative than this, plant cells would be unable to attract and/or retain moisture from the soil. At water potentials of -30 bars pressure it is suggested[25] that not more than approximately 80% of the AWSC or 70 mm could be removed.

In determination of Agriculture Capability the following climatic moisture deficits are used[28]:

Agric. Cop. Class	CMD (mm)
1	<40
2	40-115
3a	116-190

For class 3a (a = aridity is main limitation) irrigation is usually indicated. Agricultural crops tend to be less tolerant of droughty conditions than forest and native plant species.

3.5.3.2 Insects and Disease

A summary of the history of insect infestation in the area is presented in Table 3.5.6 and Figure 4.5.3[18]. In a more recent visit of the sampling sites by forest pathologists of Ministry of Forests[30] and a CFS Ranger[19], it was established that most mature stands were infested to various degrees with laminated root rot (Phellinus weirii), and/or dwarf mistletoe (Arceuthobium tsugense). On site 5A, die-back on branches of coast Douglas-fir was attributed to intensive brush control spraying, although root rot (Armillaria ostayae) was also present (see Plate A.3.41). On Site 4, near the mill, a mature maple tree was heavily infested with galls on the leaf blades (see Plate A.3.29). Mites were suspected to be the cause.

TABLE 3.5.6
Insect Infestations of the Port Alice Area
From: Canadian Forestry Service, Forest Insect and Disease Survey Internal Report, 1982

Insect	Infestation History	
western hemlock looper (*Lambdina fiscellaria lugabrosa*)	Hosts:	western hemlock preferred host; western red cedar, amabilis fir, Sitka spruce, and coast Douglas-fir also attacked during outbreaks
	1925-1927:	major infestation along west side of Neroutsos Inlet
	1928-1930:	continued mortality of trees in Quatsino region
	1944:	moderate populations in Quatsino region
green-striped forest looper (*Melanolophia imitata*)	Hosts:	western hemlock and western red cedar in fog belt; coast Douglas-fir, true firs, spruce, and pine secondary host
	1968-1969:	Quatsino region Coal Harbour to south tip of Neroutsos Inlet and east of Victoria Lake; a total of 13,500 ha affected
western black-headed budworm (*Acleris gloverana*)	Hosts:	western hemlock and amabilis fir are preferred hosts; coast Douglas-fir, grand fir, Sitka spruce and mountain hemlock may also be attacked
	Symptoms:	little tree mortality; foliar discoloration and top kill typical
	1943-1944:	north parts of Vancouver Island
	1955:	4160 km^2 at north tip of V.I. affected
	1969-1973:	1970 - spot infestation east of Port Alice 1971 - moderate to severe defoliation over 690 ha along both sides of Neroutsos Inlet; 1400 ha of light defoliation 1972 - severe defoliation of western hemlock regeneration in Port Alice area 1973 - declining infestation, scattered patches near Port Alice and Victoria Lake
conifer sawflies (*Neodiprion spp.*)	Hosts:	western hemlock, amabilis fir and lodgepole pine preferred; most conifers may be attacked
	1948-1949:	infestation near Victoria Lake, but no defoliation
	1957:	Quatsino Sound - Holberg Inlet after an infestation of black-headed budworm
	1975:	severe defoliation of western hemlock over 2 ha west of Neroutsos Inlet
	1978:	high larval populations at Port Alice

Insect damage on all sampling sites was absent or sporadic and no significant infestations were evident[32]. Visible defoliation was associated with specific segments of branches and did not involve all or most foliage per branch or tree. Distribution of dead trees was regional rather than centered around infestations. The patterns of defoliation and dead trees appeared inconsistent with patterns expected when caused by insects and disease[19].

CHAPTER FOUR
DISCUSSION

4.1 Emissions

The daily production rates averaged over each year, do not differ significantly over the period 1981-1987. However a distinct trend is noticeable in the daily emission rates of SO_2. Consequently an increasing trend occurred in the total annual emissions of SO_2.

4.2 Air Quality Trends

4.2.1 Regional Representativeness

Air quality monitors in Port Alice and Rumble Beach, and the historical sulphation plate network, provide an indication of the ambient air quality of the area. The extent to which the monitoring locations represent the location of regional maximum groundlevel SO_2 concentrations in the area is unknown. Similarly, the extent to which the monitored air quality data represent 'typical' regional air quality characteristics is unknown.

The oceanside transect of sulphation plates and SO_2 monitors provide some indication of the ambient SO_2 concentration gradients between the Port Alice pulpmill and the community of Rumble Beach. However, SO_2 concentrations impinging on these monitors do not represent the greater concentrations which are likely to occur at higher elevations where the plume centreline impinges on the mountain slopes.

Air quality monitors are at fixed locations and, as a consequence, do not register SO_2 concentrations whenever local winds transport pollutants in a direction away from the monitors. Also, they do not register SO_2 concentrations on those occasions when the plume is carried over the monitors and, because of atmospheric stability, there has been insufficient time for the plume to be mixed down to the earth's surface.

Except during periods of unstable atmospheric conditions when the plume from the Port Alice pulpmill can mix quickly to the ground, concentrations of SO_2 recorded at the Port Alice air quality monitoring site probably underestimate the actual concentrations of SO_2 in the region. The combination of atmospheric stability and hourly windspeeds result in pulpmill effective plume rise heights which are likely to vary from 50 to 600 metres. Meteorological conditions determine whether or not an existing plume will impinge on the monitoring site.

The representativeness of the monitoring network in the Port Alice area as an indicator of regional ambient air quality can be determined by establishing an extensive air quality monitoring network or by means of detailed atmospheric dispersion modeling.

The magnitude of SO_2 concentrations, frequency of SO_2 impacts, and frequency of ambient air exceedances are unknown for areas which are not instrumented with SO_2 monitors. However, these parameters can be determined by using an atmospheric dispersion model and by calibrating the estimated concentrations with SO_2 data from the air quality monitors.

The transport and diffusion of pollutants over a specific area may be simulated through atmospheric dispersion models. These require meteorological data which are representative of the area to be modeled.

4.2.2 Period 1981-1987

An analysis of air quality data has been performed by Leung[50]. Over the period of February 1981 to February 1985, the annual hourly mean ambient air quality near the mill ranged from 85 $\mu g/m^3$ to over 206 $\mu g/m^3$. The analysis of the trend over the 5 year period proved significant at $\alpha = 0.05$ (Table 4.2.1) although high variability in the measurements caused a low correlation factor. The air quality deteriorated at an estimated rate of 21.5 $\mu g/m^3$ yearly (Figure 4.2.1). In these measurements individual readings ranged beyond the measuring range of the instruments which was 2660 $\mu g/m^3$ so that the above values are an underestimation of actual values. Monthly 1-hour average concentrations ranged from 110 to 350 $\mu g/m^3$. In February 1986, the range of the instruments was altered and a reading of 4394 $\mu g/m^3$ was recorded. Leung found that excursions for levels higher than those at which vegetation injury may be expected occurred periodically. At the more remote site at Rumble Beach, annual averages, 24-hour averages, and 1-hour averages in excess of injurious levels of SO_2 occurred. Leung calculated annual mean concentrations of SO_2 at Rumble Beach for the 1981 to 1984 period. Computed averages ranged from 34 $\mu g/m^3$ in 1984 and 42 $\mu g/m^3$ in 1982, to 50 $\mu g/m^3$ in both 1981 and 1983.

Table 4.2.1 - Correlation Analysis of Monthly Ambient Air Quality at Site 4 and Months from February 1981 to February 1985

BAR

GENERAL LINEAR MODELS PROCEDURE

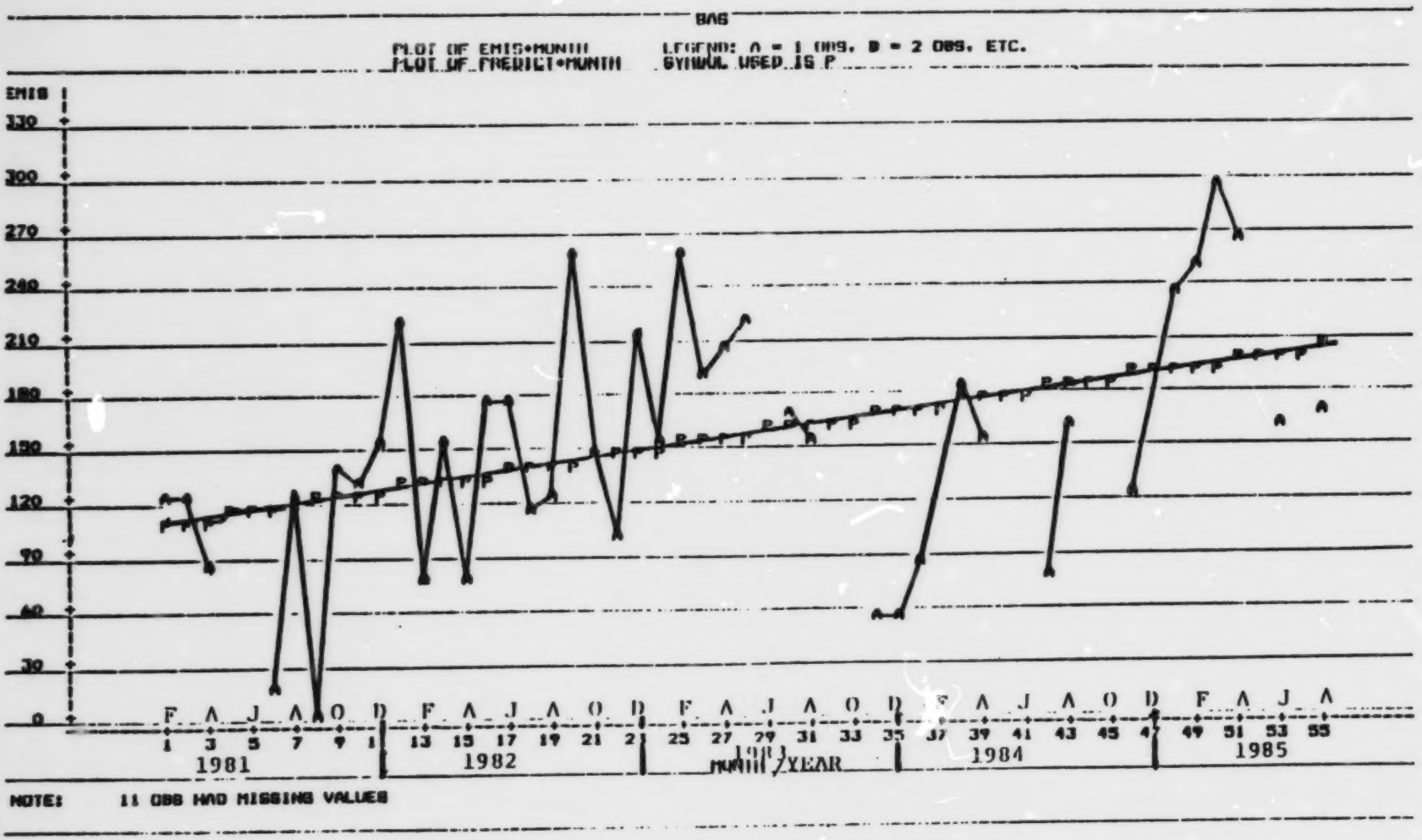
DEPENDENT VARIABLE: EMIS

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	1	32280.96145458	32280.96145458	8.93	0.0047	0.175316	40.3462
ERROR	42	151848.99399997	3615.45223809		ROOT MSE		EMIS MEAN
CORRECTED TOTAL	43	184129.95545455			60.12863077		149.03181818

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
MONTH	1	32280.96145458	8.93	0.0047	1	32280.96145458	8.93	0.0047

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > |T|	STD ERROR OF ESTIMATE
INTERCEPT	192.82277903	5.74	0.0001	17.72537013
MONTH	1.76339785	2.99	0.0047	0.59014454

FIGURE 4.2.1 Air Quality (EMIS) Trend from 1981 to 1985 at Site 4



NOTE: 11 OBS HAD MISSING VALUES

Because of the limited upper detection limit (>1335 $\mu g/m^3$) of the SO_2 monitor at this site, Leung's calculations underestimate actual annual mean concentrations. Between 1981 and 1985 the number of 1-hour, B-level exceedances recorded by the Rumble Beach SO_2 monitor ranged from 1 in 1984, to 25 in 1985. Over this period the annual average number of such exceedances was 11.

4.2.3 Long-term (1918-present)

Measurements of ambient air quality are not available prior to 1981. However, a general "ballpark" inference may be made from consideration of production rate, equipment configuration, processes and production technology, and control measures. Through comparison of present air quality with actual and estimates of emissions, and through an estimation of emissions at earlier times, general levels of air quality at such times may be inferred. Using estimated figures on sulphur consumption recovery efficiency and airstack scrubbing efficiency supplied by Western Pulp Inc.[1], the daily emission rate per ton of pulp production is estimated to be 11.1 kg/metric ton per day with the present pollution control measures in place. Without the pollution control devices, emission rates are estimated at 122 kg/metric ton per day. With the information presented in Table 3.1.1, SO_2 emissions are estimated to range from approximately 5500 kg/day in 1918 to 45,000 kg/day in 1970. By 1980, emission estimates drop to 4100 kg/day to increasing by 1986 to 5000 kg/day. Actual emission information for 1981 renders an estimated daily emission of 4200 kg SO_2. For 1982 this estimate is 4700 kg/day. For 1986 the estimated actual emissions were 21000 kg SO_2 per day. Production for 1987

increased by approximately 13%. Emission rates were not available for 1987. Barring any major changes in the distribution system (a lower stack would increase local effects). Air quality in 1981 and 1982 (resulting from 4000-5000 kg/day SO_2 emissions) may be comparable with that in 1918 (resulting from 5500 kg/day). In 1970 air emissions were estimated to be in the order of 10 times those of 1981 and 1982, and corresponding air qualities are expected. The model used to project emissions assumes a present rate of emissions of sulphur of 5 metric tons/day. In effect, Western Forest Products Ltd. has reported emissions of 10 metric tons/day[31], thus indicating that the pollution control efficiency is lower than assumed in the projections. The projected emission rates from 1978 to 1986 underestimate the actual emissions by 100% to 300%.

4.3 Bio-climate

The data indicates that no distinct dormant seasons can be defined. The period in which freezing may occur ranges from 136 days to 168 days. Within this period frosts are recorded for from 63 days to 20 days leaving from 124 days to 100 days for which no freezing temperatures occur. Daily maximum temperatures less than the threshold for biological activity >4°C) are recorded only for between 15 and 50 days. Consequently, biological activity of conifers may occur throughout the year.

Moisture deficits occur irregularly for June, July, or August, and occur mostly in July. The maximum accumulative deficit annually ranges from 0 to 135 mm (CMB). The latter occurred in 1985. This year ranks somewhat more favourably than the 1958 worst case discussed in the previous section.

favourably than the 1958 worst case discussed in the previous section.

4.4 Soil

4.4.1 Basic Soil Characteristics

Acidity of all surface horizons (as indicated by pH measurement in water) is extremely acid (<4.5)[57]. With the exception of site 6, all subsurface horizons sampled were also extremely acid or very strongly acid (Figures 4.4.3a,b,c, A.1.16a,b,c). Corresponding contents of exchangeable base cations (calcium, magnesium, sodium, potassium) are very low as are the percent base saturation values (Figures A.1.1, A.1.2).

Surface horizons high in content of leaf and needle litter have highest measured carbon, nitrogen, extractable phosphorus, and total sulphur values, along with a high measured cation exchange capacity. Carbon/nitrogen ratios, a general measure of the level of organic matter deposition rates relative to mineralization by soil microorganisms and other biota, appear somewhat high. Variations in these properties among sites do exist, however, and are discussed below.

As was expected, given the reddish-brown colours generally, extractable amounts of iron and aluminum (Figures 4.4.4a,b; 4.3.7) (by three methods measuring somewhat different mineralogical constituents) were high. Again, variations between sites are discussed below.

4.4.2 Soil Properties and Distance from SO_2 Source

A series of bar graphs allow review of variation of concentrations of selected soil parameters in relation to distance from the mill.

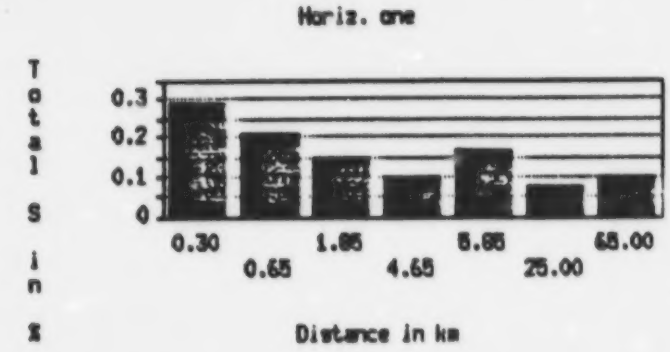
These are presented in figures 4.4.1 to 4.4.3, and in Appendix A.1.2.

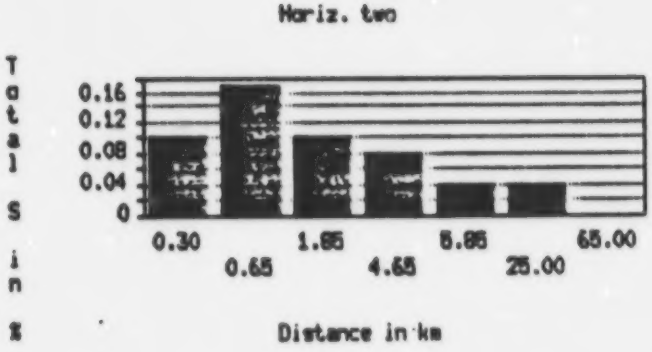
A clear trend in decreased total sulphur content of soil with distance from the mill is indicated for the surface and both subsurface horizons (Figure 4.4.1 a,b,c). The higher total sulphur value for both horizon 2 and 3 at the 0.65 km distance may indicate a higher actual exposure, perhaps due to frequency of plume impingement.

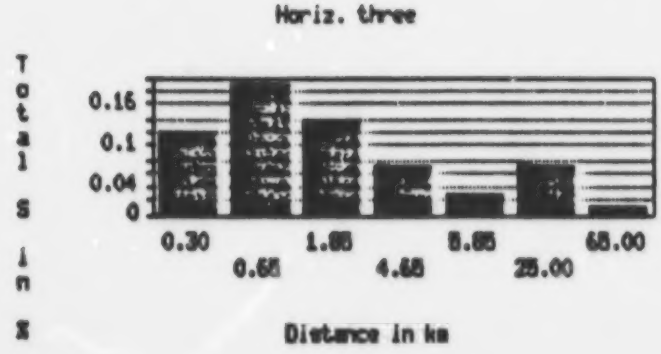
A similar trend of decreasing sulphate sulphur content with distance is observed for horizons 2 and 3 but not for horizon 1 (Figure 4.4.2a,b,c). This may be explained by the fact that sulphate sulphur is relatively easily leached to depth in soil, thus allowing subsurface horizons to more accurately reflect surface deposition. Alternatively, or perhaps in addition, sulphate extraction from the highly organic surface horizon may have been somewhat variable, results thus reflecting laboratory methodology rather than actual field soil conditions (see section 1.3.3 above for a comment on this aspect).

It is concluded that soil sulphur decreases with distance from the mill and with exposure to sulphur dioxide. These results, therefore, provide initial evidence for direct effects of exposure of soils to mill emissions. It is

Figure 4.4.1 Total Sulphur Accumulations in Soils at Distances from Mill







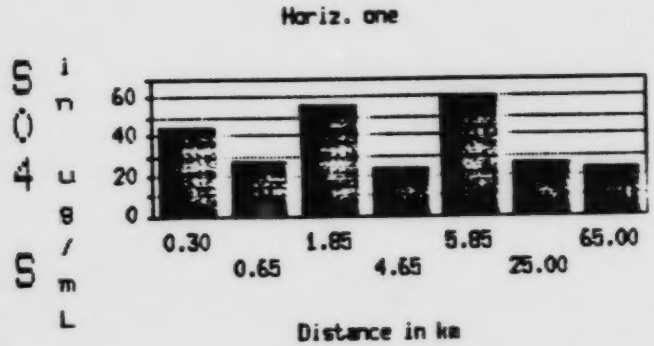
Horizon 1 = LFH

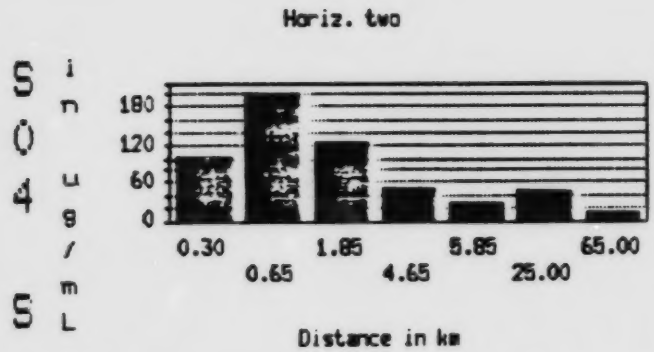
Horizon 2 = Bf_1 or Ahe

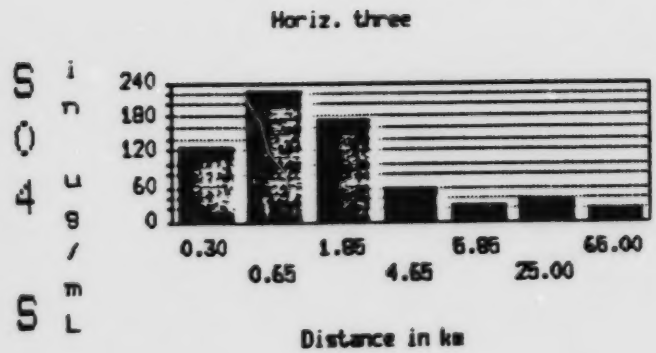
Horizon 3 = Bf_1 or Bf_2

see Table 3.4.1

Figure 4.4.2 Sulphate Sulphur in Soils at Distances from Mill







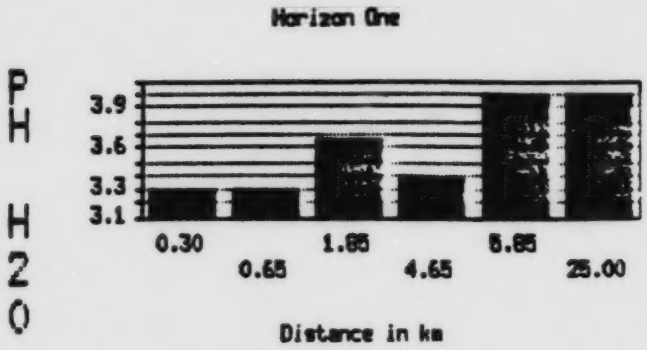
Horizon 1 = LFH

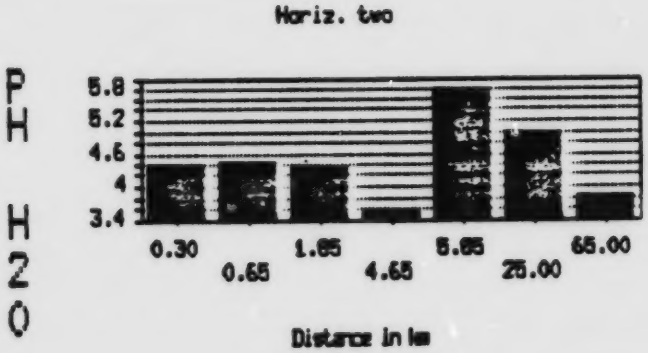
Horizon 2 = Bf_1 or Ahe

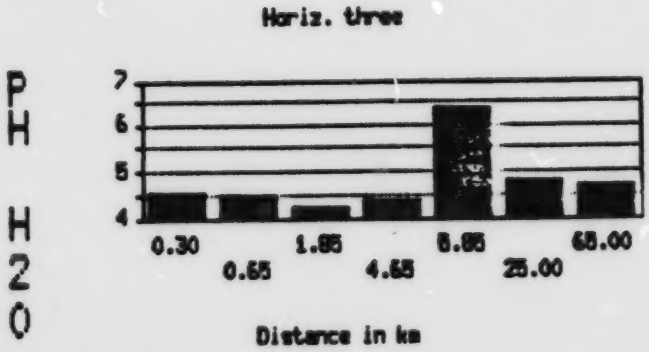
Horizon 3 = Bf_1 or Bf_2

see Table 3.4.1

Figure 4.4.3 Soil Acidification at Distances from Mill







Horizon 1 = LFH

Horizon 2 = Bf_1 or Ahe

Horizon 3 = Bf_1 or Bf_2

see Table 3.4.1

recognized, however, that sulphur is a nutrient element and higher levels in soils may, in fact, enhance growth.

Soil exposure to sulphur dioxide can decrease soil pH. Associated changes may be significant and include: reduced organic matter mineralization and reduced availability of nitrogen and phosphorus, increased leaching and lower contents of base cations, and increased solubility and perhaps plant toxicity of trace elements.

Surface horizon pH values in water and in 0.01M calcium chloride show a marked increase (reduced acidity) with distance (Figures 4.4.3a, A.a.16a). However, the trend is not as consistent for deeper horizons (Figures 4.4.3b,c, A.1.16b, c).

Exchangeable calcium and exchangeable magnesium values show very similar increasing trends with distance. For surface horizons, values increased with distance from the mill (Fig. A.1.17a, A.1.1a). Subsurface horizons (2 and 3) followed a less consistent trend (Fig. A.1.17b,c;A.1.1.b). These trends are mirrored (Fig. A.1.2) closely by base saturation, a measure of overall content of basic nutrient cations.

It is a well documented observation in soil chemistry that on soil addition of acid containing constituents, basic nutrient cations such as calcium and magnesium are exchanged on soil particle surfaces, by acidic cations such as hydrogen and aluminum. Such reactions appear to be occurring in surface soils in the Port Alice area.

Measured lime requirement values, often used as rough measures of neutralizable soil acidity by a "quick test" method, showed no clear trends. Though surface horizons at the three closest sites to the mill had lowest lime requirements (LR 5.4) and the four sites furthest from the mill had highest requirements, a trend with distance is not shown (Figure A.1.3). Similarly, subsurface horizons (Figure A.1.4) showed no explainable trends in a measure of lime requirement (LR 6.0). Lack of explainable trends may be attributed to the "quick test" nature of the method and the variety of factors[74] potentially affecting it.

Extractable copper and zinc, and exchangeable aluminum were selected as indicators of effects from possible acidification of soils due to mill emissions deposition. Copper and zinc are often considered chemically similar enough in soils to be analyzed for by similar methods[75]. Increased exchangeable aluminum results from acidic inputs.

Extractable copper showed a relatively consistent decreasing trend with distance from the mill in the surface but not subsurface horizons (Figures A.1.5). This trend was not observed, however, for either extractable zinc (Figure A.1.6) or exchangeable aluminum (Figures A.1.7). Zinc in the surface horizon in fact appears to show a slight increasing trend with distance.

Though a variety of basic soil properties were measured only several properties are likely to show sensitivity to acidification. Total nitrogen was plotted.

As noted, organic matter mineralization may be decreased with acidification. Resultant total nitrogen might therefore be

increased since formation of leachable mineral forms might be reduced. Figure A.1.8a shows a decreased surface total nitrogen with distance from the mill, perhaps reflecting reduced mineralization and higher build-up of litter near the mill. Subsurface horizon trends are not consistent. (Figure A.1.8b,c).

4.4.3 Relationships Between Soil Properties

The anticipated negative relationship between total sulphur and soil pH for individual horizons as well as for all horizons taken together (Figures A.1.9) was observed. The same negative relationships between total sulphur and exchangeable soil calcium is noted (Figure A.1.10a,b). This result tends to corroborate the evidence for soil acidifying effects of sulphur deposition from mill emissions as observed previously for the trend plots with distance.

The expected general positive relationship between percent base saturation and pH (Figures A.1.11) and between exchangeable calcium and pH (Figures A.1.12) was also observed. Thus with increasing acidity, a decreasing basic nutrient cation status of the soils was measured.

When considering soil base saturation in relation to sulphur content directly, a general trend of percent base saturation decrease is noted with increasing sulphur content. This trend is apparent when considering surface soils alone and when considering all horizons combined (Figures A.1.13).

Though not observed for the surface horizon taken alone, all horizons taken together (Figure 4.4.4) displayed increasing

exchangeable aluminum content with increasing acidity (decreasing pH). Given that acid rain impact as well as other literature points to toxicity effects of plant available aluminum[81,82], soil acidification effects on plant available aluminum appears to warrant concern in the Port Alice area.

Extractable zinc, another indicator trace metal expected to increase in soil with acidification, did indeed show increasing trends with decreasing soil pH in the Port Alice area (Figure A.1.14). Though an inconsistent trend with distance from the mill was noted (Figure A.1.6) the general relationship with soil pH is of interest.

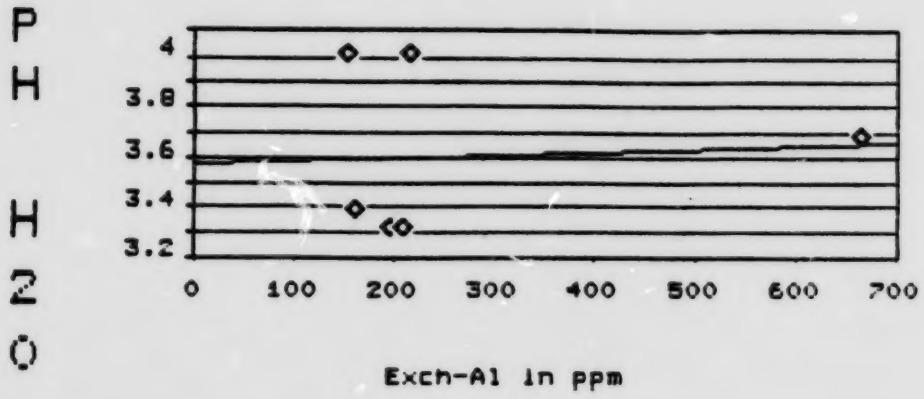
As was the case for zinc, though no clear trends of lime requirement with distance were noted, lime requirement showed a strong negative relationship with pH (Figure A.1.15).

4.4.4 Port Alice-Soil Concentrations Versus Other Soils

Literature values for soil constituents from studies in Canada and other countries can be compared to values for soils in Port Alice. As well, some values are available for other studies in British Columbia. However, attempts at comparison of such variables as soil pH, percent base saturation, exchangeable calcium and magnesium, total nitrogen, lime requirement etc. would not be meaningful unless information were available on many aspects of the setting and natural environment of the soils. Emphasis will be on sulphur and trace metal contents.

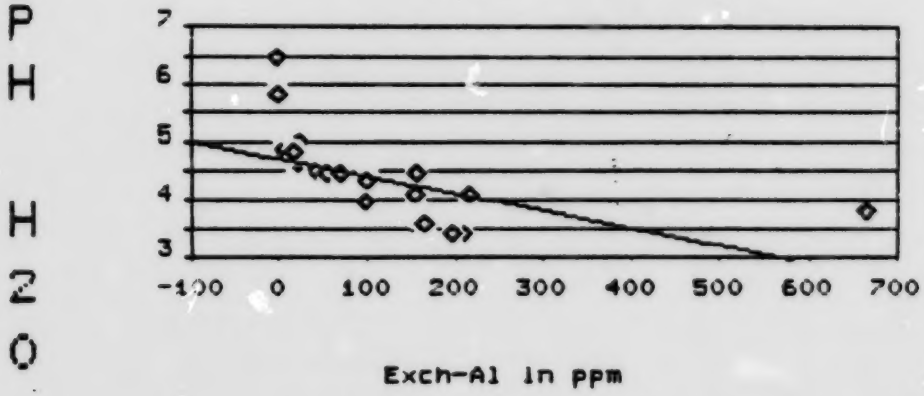
Figure 4.4.4 pH - Related Toxic Metal Concentrations: Aluminum

Horiz. 1



PORT ALICE SO-2 STUDY

Horiz. 1,2,3



Horizon 1 = LFH

Horizon 2 = Bf_1 or Ahe

Horizon 3 = Bf_1 or Bf_2

see Table 3.4.1

It is generally agreed that total sulphur in soil normally ranges between 100 and 500 ppm[83,84]. Organic soils may contain as much as 5000 ppm, however. Surface soil horizons in a study in the area of the Trail, B.C. smelter range between 230 and 1760 ppm while subsurface samples ranged between 130 and 810 ppm[85]. Two surface soil samples in the area of the Kimberley, B.C. Sullivan mine concentrator and fertilizer plant had sulphur values of 1350 and 1600 ppm while subsurface samples ranged from 70 to 460 ppm. Pre-operational monitoring of soils in the area of the Afton copper mine and smelter at Kamloops B.C. showed values in the range of <30 to 460 ppm. One value shortly after operation began reached 940 ppm.

Comparison of the above literature and other B.C. soil monitoring results, some from areas of expected industrial contamination, with Port Alice area soils indicates the soils to be abnormally high in total sulphur content (Figures 4.4.5, A.1.13).

Exchangeable aluminum in Port Alice soils by the method used in this study ranged between 154 and 666 ppm (surface samples) and 0.21 and 165 ppm (subsurface samples), with a mean of 134 ppm for all samples. Hoyt and Nyborg, using the same methods for 40 acid soils,[86] measured a range of 0.7 to 700 ppm with a mean of 101 ppm. As an indicator of the usefulness of this measure of exchangeable aluminum, these workers determined a correlation coefficient of 0.87 between the variable and yield response of barley to liming. Values for alfalfa and rape crops were 0.58 and 0.52 respectively.

Exchangeable aluminum measured in Port Alice soils would appear to be at or above levels to be expected in very acid

soils. Data is not available to assess likely response of forest or crop species to liming and therefore likely aluminum or other elemental toxicities.

Extractable copper values (0.1N. HCl) ranged between 0.21 and 3.43 ppm (surface) and 0.10 and 14.68 ppm (subsurface samples) in this study. This compares to a range of <0.03 to 16.8 ppm for a recent soil monitoring study in the Greater Vancouver Regional District Area - GVRD[87]. It can also be compared to values in Trail, B.C. area where soils ranged from 1 to 170 ppm[85]. Extractable copper values in the Port Alice area do not appear to be high when compared to values measured in other B.C. soils.

Extractable zinc values in this study ranged between 2.56 and 15.79 ppm (surface) and 0.10 and 2.92 ppm (subsurface samples). In the recent GVRD study[87], zinc measured by the same methods ranged between 1.06 and 198 ppm for surface and subsurface soils. Trail area soils ranged between 15 and 816 ppm[85]. Extractable zinc values do not appear to be high when compared to results from other B.C. studies.

4.5 Vegetation

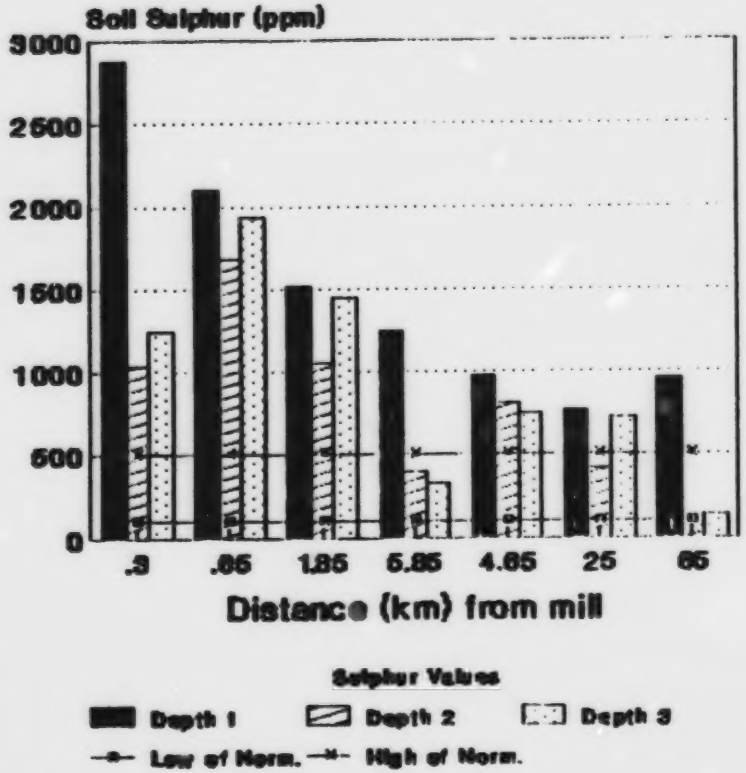
4.5.1 Air Quality Effects

Effects of SO_2 dosages on vegetation may be acute or chronic.

Acute effects result from injurious single events of relatively high concentrations of SO_2 in the atmosphere. Symptoms of acute effects are described. The periods and

Figure 4.4.5 Port Alice Soil Sulphur at Distances from Mill

(Values Relative to Normal)



For Depth see Table 3.4.1

magnitude of acutely injurious levels can be determined only from continuous measurements. Specific conditions of climate the developmental stage and degree of metabolic activity of the receiving plant further determine its susceptibility to SO_2 injury.

Chronic effects may result from repeated or prolonged exposures of plants to SO_2 concnetrations in the atmosphere. Although the various "means" provide some insight in the patterns of exposure, the role of individual events, and of repetitions of exposures remain obscure. Similarly the incidence of periods of no exposure to SO_2 concentrations resulting from industrial shut-downs or from changes in wind direction would depress mean concentration values (Section 3.2), thus disguising the actual exposure regimes (or shorter-lived and higher atmospheric concentrations) to atmospheric SO_2.

Maximum sensitivity of B.C. plant species to SO_2 has been found[80] to be approximately 390 $\mu g/m^3$ for short duration (1-5 hrs.) averaged exposures, 360 $\mu g/m^3$ for intermediate duration (6 hrs.-3 days) averaged exposures, and 16-18 $\mu g/m^3$ for long-term duration (2 weeks to annual) averages. Exceedance frequences of 350 $\mu g/m^3$ at the Port Alice monitoring station (Site 4) in the period from 1981 to 1987 are presented in Table 4.5.1. Fewer potentially injurious exceedances occurred in 1981 due to industrial shut-down. The exceedance frequencies are likely to be higher in areas of maximum impact.

Lichens, Douglas-fir, and true fir species are among the most sensitive of species. The observed effects on species

diversity (Section 4.5.2) are in agreement with the expectations based on species sensitivity and frequent exceedance of the 350 µg/m injury threshold for the vegetation.

4.5.2 Visible Symptoms

Visible symptoms were present at sites east and north of the mill. The site near Port Hardy (Site 7) and that in the Tsitika watershed (Site 8) were free of any visible symptoms. Site 2, near the south end of Neroutsos Inlet was affected by dwarf mistletoe. However, the infection was not unusual for mature stands and it was not considered to have been aggravated by effects from air pollutants.

4.5.3 Effects on Species Diversity

Species diversity was affected to degrees varying with the distance to the mill in the downwind direction. The most severely impacted area being near Site 4. Here, evergreen trees, western hemlock, coast Douglas-fir, western red cedar, and amabilis fir have been mostly killed with only snags and a few severely injured western hemlock remaining. More tolerant broadleaf species (red alder, bitter cherry, common periwinkle, and others) remain in various stages of health. Epiphytic lichens and lichens normally "coloring" the bark of trees were absent, leaving a typical "lichen desert" (Sernander[34]). Tree trunks were typically brown or green with apparent algal growth due to eutrophication. Although observations were sporadic, an absence of coast Douglas-fir and amabilis fir also marked the area of substantial impact. Being a seepage-site, the absence of western red cedar may

Table 4.5.1

Port Alice Sulphur Dioxide Exceedances of 1-Hour Mean Level of 350 $\mu g/m^3$ for 1981 to 1987

	1981	1982	1983	1984	1985	1986	1987
January	-	53	59	104	100	52	111
February	56	0	136	3	15	83	122
March	65	67	89	0	1	124	133
April	39	75	60	17	75	83	114
May	64	87	100	18	114	112	88
June	1	137	75	34	129	-	83
July	-	46	124	6	158	-	100
August	-	86	112	94	175	76	67
September	-	44	123	68	150	110	72
October	0	98	120	33	28	190	146
November	-	110	81	27	90	126	57
December	4	67	102	35	87	158	66
	229	870	1181	439	1122	1114	1159

also be regarded as suspicious. Western white pine was also absent. However, white pine blister rust may be involved.

4.5.4 Effects on Remaining Plants

Visible injury includes collapsed tissue, a general yellowingof the leaves (chlorosis), interveinal necrosis, acute tip and foliar necrosis and defoliation, and partial or complete die-back of trees (see Plates A.3.2 to A.3.11 and A.3.26, A.3.36, A.3.37).

The visible symptoms on foliage were classical[13]. Interveinal chlorosis and necrosis was observed on many deciduous species (see Plates A.3.25, A.3.27, A.3.28, A.3.35, A.3.44, A.3.51) including red alder, trailing blackberry and elderberry. Symptoms were also observed on evergreen foliage of salal, swordfern and deerfern. Symptoms on orchard grass appeared less definite. Tissue collapse, giving a "soaked" appearance, prior to browning and necrosis, was observed on deciduous foliage of buttercups and elderberry (Plates A.3.23, A.3.33, A.3.34, A.3.45). At the time of inspection, salmonberry was already totally devoid of foliage (Plate 5.35B,) while red alder had experienced a substantial premature loss of foliage (Plate A.3.24).

Defoliation of western hemlock was widespread and extending to (and probably beyond) the Jeune Landing site (Site 5B). Defoliation might involve all of the exposed segments of the trees in the most severe areas (Plates A.3.11, A.3.14, A.3.15, A.3.36), or it might involve only the growth of specific years. Where current years growth had escaped acute injury, it often was retained until such time that toxic

levels of accumulation had occurred. It is not clear at this stage if the sulphur levels in the tissues (sulphate in vacuoles) are affecting leaf retention, or if leaf drop is a delayed response to earlier subacute exposures, or if leaf drop is the result of chronic exposure to intermediate levels of ambient sulphur dioxide. Skye[33] suggests that chronic exposure may lead to the destruction of "chlorophyll a" by photo-oxydation and the formation of "phaeophytin a", while high concentrations destroy the plasma in the cells. The proportion of foliage to twigs is likely to vary with site conditions as well as with age of twigs and species. However, the limited data of Table 3.5.3 suggests that for western hemlock a foliage:twig ratio in excess of 5.0 implies reasonably favourable conditions for full grown current years' (yr = 0) foliage. Ratios below 4.0 seem associated with twigs that have been visibly defoliated. For 1 year foliage, ratios of 3.0 or less appear indicative of defoliation. Ratios appear higher for open grown branches than for branches inside the canopy. However, the defoliation effect of sulphur dioxide may be more pronounced on exposed branches. In some cases, where exposure led to injury of foliage, a distress response may result in the formation of dwarfshoots (epicormic shoots) with needles. If the exposure persists, such foliage is likely to be lost. However, the dwarfshoots may (temporarily) raise the foliation index to values typical for no defoliation.

Die-back of current year's growth was symptomatic throughout the area investigated. It appears to reflect acute injury to the growing tips of branchlets. The terminal segment of the branches appears rapidly desiccated causing it to be contorted and often curled-back and light colored, somewhat

reminiscent of a "hog's tail" (see Plates A.3.12, A.3.17, A.3.43). This effect seemed to become evident when the current year's growth had reached a reasonable degree of development, possibly indicating that the foliage is less susceptible in the early stages of development as was found for many other species[34]. Combinations of acute and chronic die-back may cause several years of foliage or all foliage tobe killed, eventually leading to death of all or part of the plant (Plates A.3.11, A.3.14, A.3.15, A.3.36).

Total kill of forest trees was predominant in the vicinity of the mill (Plates 1.1,5.11, 5.14, 5.15, 5.36) and became less pronounced with distance to the mill. It appeared that tree kill was most pronounced in a north western direction along the coast shore and across Neroutsos Inlet. Frigon Islets were observed only from the east shore of the Inlet (Plate A.3.7), and appeared to have sustained substantial impact. A closer on-site examination is required to determine if other causes have contributed. Observations of kill and injury patterns and a single observation of the plume suggests that impacts may be expected along the western side of Neroutsos Inlet. The limited number of samples and observations do not permit an estimate of the extent of the impacts. A more comprehensive study of the distribution of injured trees and plants and of the impacts of air pollution on the growth of species is required before an estimate of the amount of impact can be made.

4.5.5 Sulphur Content of Foliar Tissues

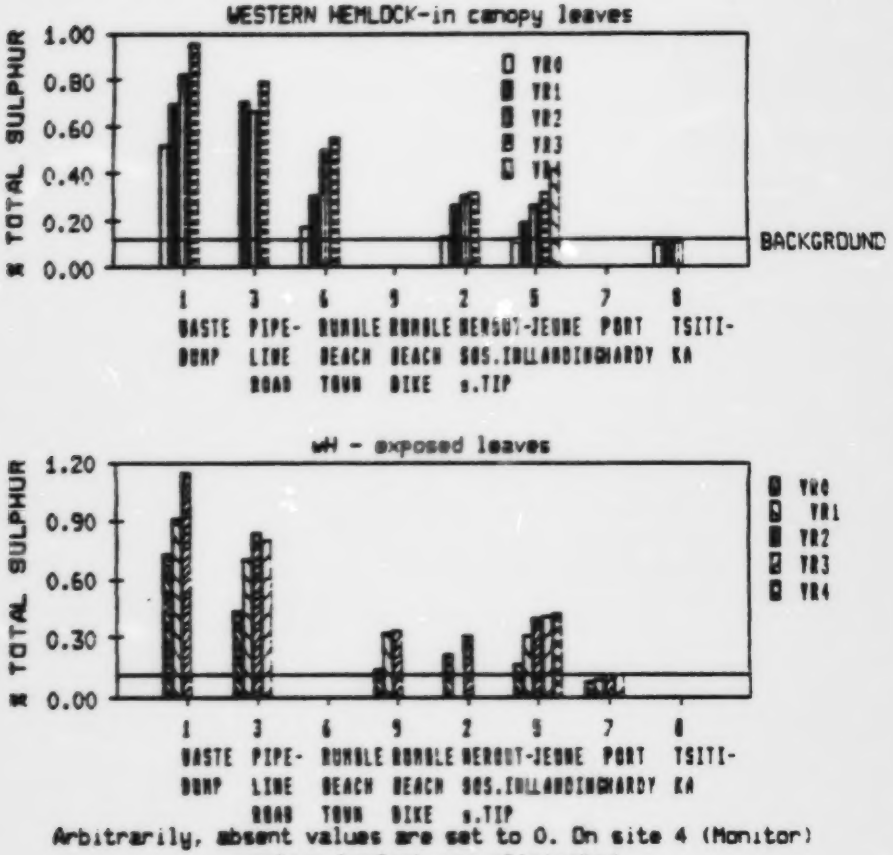
The sulphur content of foliar tissue and some stem tissues is presented in Table 3.5.4. The sulphur content varies from

species to species, and with the age of tissues. Furthermore, position of the foliage in relation to the canopy may account for variation. The growth rate of the plants is a function of its site (ecosystem), and the rate of sulphur dioxide uptake will vary accordingly. An evaluation of sulphur in the soil is prepared by Wiens in Sections 4.4. of this report. Sulphur content of tissues was highest, (1.14% total sulphur[29]), for evergreen western hemlock foliage of 2 years-old (i.e. 3 growing seasons and intervening periods), from branches freely exposed to the airflows on Site 1. Site 4 was located closer to the mill site. However, western hemlock had been largely eliminated from this site and no foliage samples were obtained. Background ("clean air") levels for western hemlock range from 0.08% in current growth to 0.12% total sulphur in 2 year-old foliage. For amabilis fir these values tend to be slightly lower (0.06-0.09%). Western white pine appears slightly higher (at 0.12%) than western hemlock, while coast Douglas-fir appears even higher (0.13-0.20%). Bryophytes rendered among the lowest measurements, ranging from 0.04% to 0.06% total sulphur. These values coincide with background values reported in the literature[34,35]. Differences between species occurred on similar sites and are not likely due to differences in soil[80].

For western hemlock, the relationship between sulphur content of the tissues and the sampling sites is depicted in Figure 4.5.1 for age of tissue and position in the canopy. Total sulphur content increases with age of the foliage. Foliage sheltered within the canopy or crowns of trees tends to be somewhat lower in total sulphur than foliage from branches projecting into the open. Sulphur content of foliage is

Figure 4.5.1 FOLIAR-TISSUE SULPHUR AT SELECTED SITES

Sites ranked in order of increasing sulphur content.



Arbitrarily, absent values are set to 0. On site 4 (Monitor) western hemlock was eliminated.

related to the atmospheric dosages of SO_2. The dosages are a function of emissions, wind direction and duration, and distance from the source. Sites 1, 4, 6, and 5 are located approximately in a line north from the mill, and differences in dosage may be primarily a function of distance. (Note that it is not implied that such dosages are necessarily representative of a dominant wind direction nor of the area of impact (see Section 4.2.1).

Western hemlock has been eliminated from Site 4. A theoretical value for total sulphur could be extrapolated if sampling stations were scaled along the X-axis according to their distance from the source. However, as we cannot account accurately for the dosages received at each site, the sites are ranked along this axis, and it is only possible to conclude that theoretical sulphur contents at Site 4 would exceed those of all other sites, if such levels would not have coincided with lethal toxicity of the atmosphere and/or of the sulphate contents of the tissues. Although Site 3 was located southeast of the mill, it appeared to be impacted proportionally to its distance to the mill. This may reflect that:

(a) the site, being located in the same "basin" as Sites 1 and 4, is subject to the same atmospheric dosage regimes. Hence, the basin would tend to fill before the wind transports the materials. Or,

(b) dosage results from a similar probability of occurrence of winds from the northwest as winds from the south.

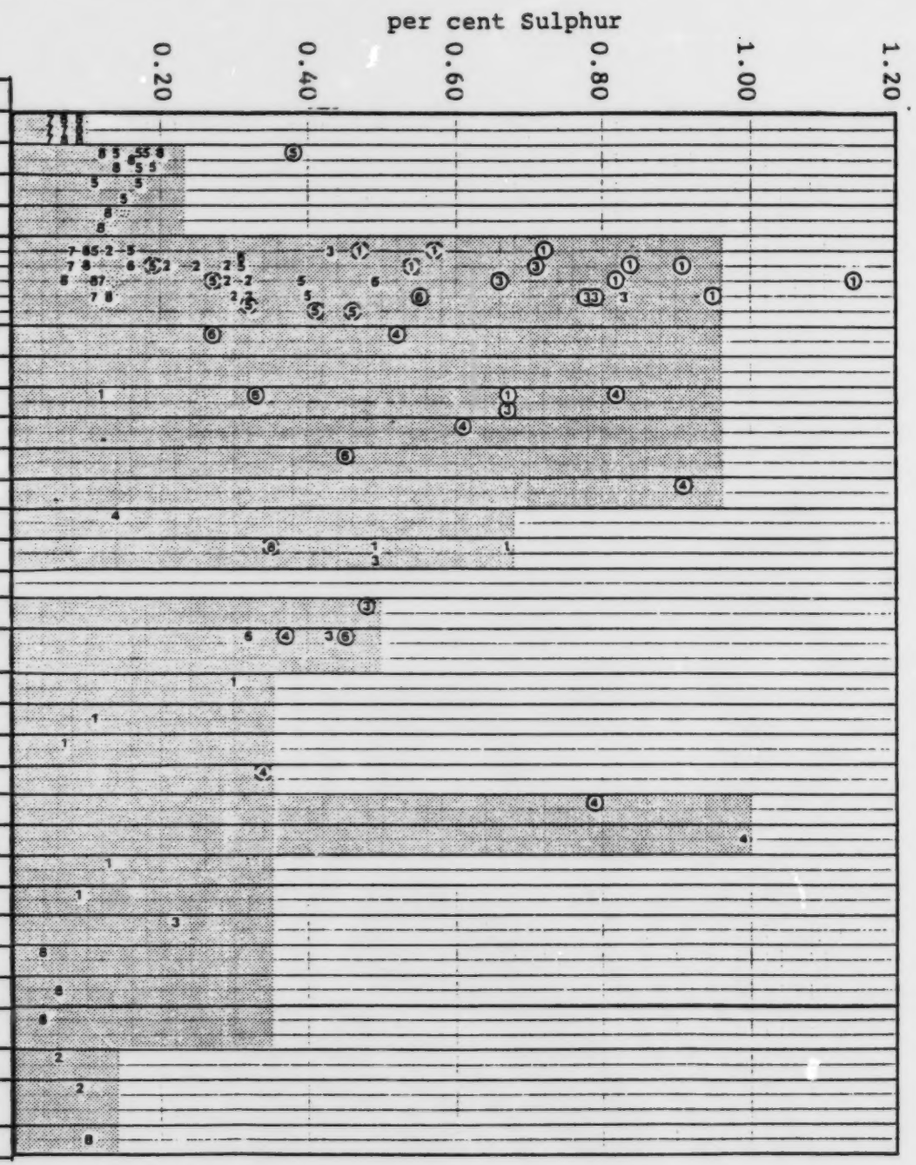
In contrast Site 2, located south of the mill, ranks after Site 6 and barely before Site 5, both of which are at

considerably greater distance. Availability of wind data would permit a more precise prorating of distance by probability of occurrence to estimate dosage. Some on-site observations of air movement suggest that the prevalent wind may be blowing more into a northwestern direction across the inlet, in which case, west of the inlet vegetation injury may extend further. Site 9 is located upslope from site 6 at approximately the same distance from the mill. Somewhat lower total sulphur in tissues at this site as compared with that of Site 6 and Site 5 (which is approximately 5 km further from the source) may indicate less frequent and/or lower concentrations of exposures to SO_2 upwards from the townsite. Sites 7 and 8, which are located well outside the direct influence (long range transport excepted) of the Port Alice mill, show low total sulphur content with minor increases with age of foliage. These represent typical background levels relating directly to sulphur uptake from the soil for normal growth and life-processes.

Foliage develops and grows to maturity in the first year. Under favorable environmental conditions foliage is retained for up to 5 to seven years (Table A.2.1). A theoretical estimate of the annual contribution of $SO_4^=$ from foliage loss to the forest floor ranges from 10-20 kg/ha in a pristine environment to the order of 125-250 kg/ha in the highly affected areas such as in proximity of the Port Alice mill (see Appendix A.2.2).

Figure 4.5.2 displays the relationship of the species, the total sulphur content of its foliar tissue, and the appearance of injury for each site, and the following is

		VEGETATIVE COMPONENT	Tolerance	Symbol
TREES		amabilis fir	VS	amF
		coast Douglas-fir	S	cD
		western red cedar	S	wC
		white pine	S	wP
		western hemlock	VT	wH YR 0-4
		red alder	T	rA
	Fruit	wH Cones		
SHRUBS		salal	VT	GS
		blackberry	VT	Ru
		elderberry	VT	Sr
		Scoulér's willow - foliage	VT	Sxsf
		Scoul. willow - twigs YR0	T	SxSO
		red blueberry	T	Vp
HERBS	Ferns	deerfern	T	Bs
		swordfern	T	Pm
	Other	sedge - foliage	MT	Cf
		sedge - roots	MT	Cr
		sedge - straw	MT	Cs
		orchard grass	MT	Dg
		buttercup	VT	Ran
		periwinkle	VT	Vm
		rush - foliage	MT	Lup f
		rush - roots	MT	Lup r
BRYOPHYTES	Mosses	Dicranum moss	S	Df
		layered moss	S	Hls
		Hypnum moss	S	Hoc
		slender pipecleaner moss	S	Rhl
	Lic-chens	oldman's beard	VS	Als
		Parmelia lichen	VS	Prs
Paper Bag				



LEGEND

	LIMIT
VT = Very Tolerant	.90%
T = Tolerant	.75%
MT = Mod. Tolerant	.35%
S = Sensitive	.25%
VS = Very Sensitive	.15%

(2) Sample with visible injury from indicated Site (2)

(2) Sample with possible injury from indicated Site (2)

Sensitivity grouping of species

Figure 4.5.2 Foliage Sulphur Content and Visible Injury for Species in Relation to their Sampling Sites

apparent. The high values are associated with evergreen (needle or broadleaf) plant. The highest levels in foliage are associated with Site 1 (1.14%). Greater exposures, such as may be found on Site 4, are lethal and lead to the elimination of western hemlock. By arranging species according to their higher levels of sulphur content in foliage, tolerance groupings may be suggested. These groupings are based on survival tolerance rather than injury thresholds.

Periwinkle and buttercup are very tolerant. Periwinkle did not display injury symptoms when accumulations of nearly 1.0% sulphur occurred. Western hemlock and a number of broadleaf deciduous species also appear very tolerant, although injury symptoms appear near 0.5% total sulphur. Deerfern, red blueberry, and swordfern appear tolerant up to accumulations of approximately 0.75%, with injury symptoms visible above approximately 0.35%. Some monocotyledons (grasses and sedges) were found to have lower total sulphur content with possible injury apparent at 0.35%. In spite of high exposures (Site 1), mainly plants of low sulphur content occurred. It is not clear if the species have low tolerance, and therefore are eliminated when sulphur content builds up, or if the plants have effective controls preventing sulphur accumulations in the tissues. A group of sensitive conifers corresponds to sulphur levels of less than 0.25%, with amabilis fir present only where tissue sulphur levels are barely above background values.

The suggested sensitivities must be regarded with reservations as sample sites are selected and few in number. Under these conditions assumptions of sufficient area of

sampling and adequate sampling intensity to ensure presence of all species over the full dosage gradient are invalid. But, the presentation here illustrates the methodology and to what extent these findings support the findings in the literature[36,12].

4.5.6 Other Causes of Vegetation Injury and Damage

Vegetation may be injured or killed from a variety of natural and man-made causes. Mechanical damage from wind, snowloads and hail storms occurs. Senescence and stand decadence are normal natural processes of older vegetation. Disease and pest infestations, may reach epidemic proportions and cause temporary impacts on growth or even death of the forest cover.

4.5.6.1 Climatic Drought

Marsh[20] indicates the occurrence of 3 significant drought periods, the most severe drought occurring in 1958. He determined that in 1958 the permanent wilting point for agricultural crops (-15 bars or approximately 70% of AWSC) might have been reached by May 24 and again by June 2, and remained below this level until the end of August (see Figure 3.3.11). Climatic energy to remove up to 80% of AWSC free water from the soil occurred by June 10. Hence, the actual removal of 80% of the soil moisture (bound to the soil) occurred sometime after this date. The 80% removal of soil moisture corresponds to -30 bars water potential which is regarded as the permanent wilting point for trees. Hence, such drought conditions may have prevailed for some time (less than 80 days). The climatic moisture deficit rose as

high as approximately 300 mm (Figure 3.3.11). Climate data for 1981-1985 (Section 3.3.2) indicate drought stress (CMB = 135 mm) for 1985. Although moisture stress was evident, no large-scale die-back has been observed. For agricultural production such a drought would represent an aridity limitation for crop growth. The maximum CMD may be regarded as an index of the energy available to remove water from the soil when moisture is freely released from the soil. A precise determination of the actual soil moisture is possible only after more detailed measurements of soil properties.

If drought in this "worst case" scenario indeed had exceeded critical intensities, a large scale die-back of the forests would have been evident. Although dating of snags and tree ring analyses have not been performed, there is no visible evidence suggesting such uniformity in time of death was in effect. Also, stands of older trees occur throughout the area, suggesting that no critical drought was in effect. Furthermore, it may be projected[20] that the drought would have been more intensive eastwards. As no evidence exists of large-scale death of forests in that area, it appears unlikely that killing droughts would have occurred in the Port Alice area.

Insufficient information is available to determine if the pattern of dead snags corresponds to the path(s) of the emission plume.

4.5.6.2 Soil Acidification

Deterioration of vegetation may result from the alteration of the soil characteristics. Further lowering of pH of the soil

may adversely affect the availability of plant nutrients to the roots as well as affect the active uptake functions of the plant root tissues. The loss of soil nutrients may adversely affect the nutrient status and the nutrient balances that were suitable for the original plant cover. Species previously suited to the local conditions may no longer grow or reproduce. Nutrient deficiencies may result in reduced productivity. Such deficiencies may also arise from a blocking of the normal mineral cycles by inhibition of soil-micro organisms and symbiotic functions. Nitrification and drought-tolerance may become affected.

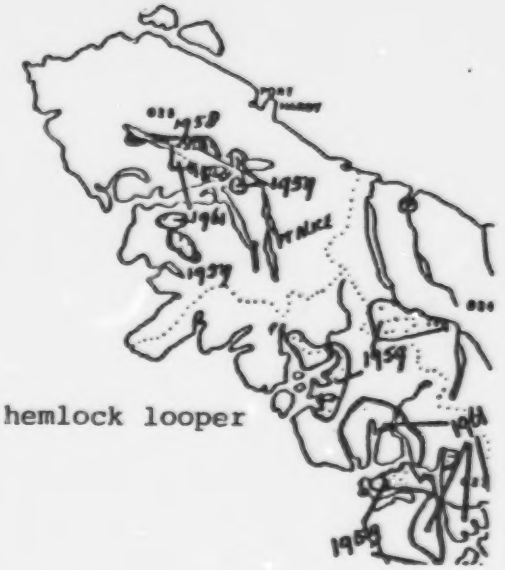
Mobilization of metals to toxic levels in the soil may inhibit root growth and uptake of nutrients, soil moisture, and make trees more susceptible to wind throw. Soil-induced stress on plants may weaken the plants' defences against pathogens and insect attaques.

4.5.6.3 Insects and Disease

A number of infestations of insects were recorded for the area[18] (see Figure 4.5.3). Also, moderate effects of a number of pathogens are in evidence[30]. However, recent defoliation and die-back of western hemlock and others was not closely associated with occurrence of insects[19] and/or disease[30]. On Site 5, near Jeune Landing, injury to coast Douglas-fir regeneration was attributed to intensive brush control spraying and the occurrence of root rot. The sample of Site 2 at the south end of Neroutsos Inlet was infected with dwarf mistletoe.

The general distribution pattern of dead branches and snags is not consistent with the pattern of historical insect

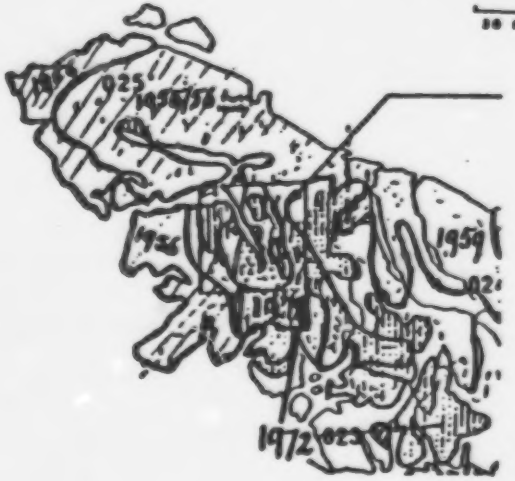
hemlock sawfly

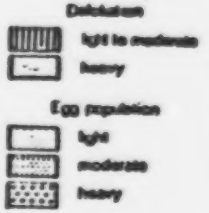


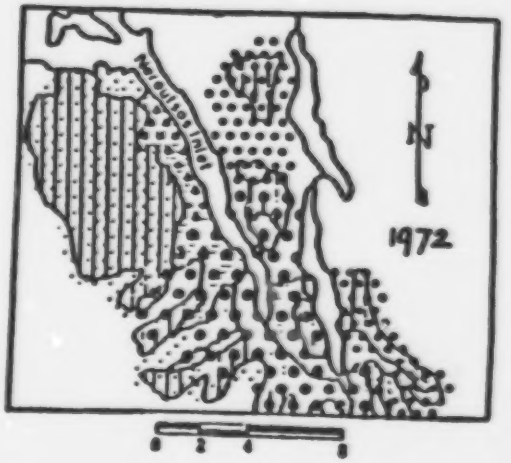
hemlock looper

green-striped forest looper

VANCOUVER FOREST DISTRICT
VANCOUVER ISLAND SECTION







blackheaded budworm

Figure 4.5.3 Insect Infestations and Year of Occurrence (From FIDS, CFS, Environment Canada)

outbreaks. The pattern of defoliation (specific years) was inconsistent with the usual patterns of insect damage. The relative "universality" of injury and damage without clear "regard" for ecosystem differences further supports that the causal agent is more universal, such as effects from atmospheric conditions.

Acute injury to the leaves and branches leaves the plant with potential "wounds" and scars through which pathogens can enter the plants. It appears, therefore, that forests injured by SO_2 are predisposed to infections. However, it is not known what the direct effect of SO_2 on the pathogens is. This may vary with concentrations. High concentrations are likely to be toxic to the pathogens as well. At lower concentrations pathogens may be inhibited or stimulated, and a shift in pathogen abundance may occur.

4.6 Public Health

4.6.1 Health Effects

Sulphur dioxide effects on the health of people may include nasal irritation and mucus secretion, tracheal and bronchial constriction and respiratory stress. More subtle health effects may result from prolonged exposures to lower concentrations. Sensitivity to sulphur dioxide is higher in individuals suffering with cardiac or respiratory disease. The adverse effects of sulphur dioxide on health may be magnified by the presence of suspended particulate matter, and possibly nitrogen dioxide or ozone, which may also lower tolerance thresholds. To date sulphur dioxide has not been shown to be carcinogenic. Sulphur is readily excreted in the

urine, and does not accumulate in the body. Several studies have indicated a possible relationship between residence in an area of heavy SO_2 pollution and mortality from all causes and from respiratory diseases. However such evidence is not unequivocal.

4.6.2 Air Quality Levels for Health

Various regulatory jurisdictions have set air quality objectives based on thresholds for environmental impacts, including injury to certain vegetation groups, human comfort and health, and sensitivities of materials and structures.

The Clean Air Act (Environment Canada, 1981) defines "Maximum Acceptable Level" as follows:

The Maximum Acceptable Level is intended to provide adequate protection against effects on soil, water, vegetation, materials, animals, visibility, personal comfort and well-being (Federal-Provincial Advisory Committee on Air Quality, April 1987).

and recommends the following Maximum Acceptable Levels:

1-Hour Average 900 μ/m^3 - will help prevent taste and odour discomfort to sensitive individuals.

24-Hour Average 300 μ/m^3 - will help prevent (adverse) effects on health when in conjunction with low suspended particulate matter in air.

1-Year Average 60 μ/m^3 - will minimize the occurrence of chronic effects in natural forests.

The World Health Organization, also, set a standard of 60 μ/m^3 for a 1-year average. The U.S.A. has set National primary Standards of 365 μ/m^3 for a 24-Hour Average, and 80 μ/m^3 for a 1-Year Average. A National Secondary Standard is set at 1300 $\mu g/m^3$ for a 3-Hour Average. 1-Hour Average Standards for individual states is 665 μ/m^3 or 260 μ/m^3. The median values throughout the world are:

1-Hour Average 900 μ/m^3
24-Hour Average 300 μ/m^3
1-Year Average 60 μ/m^3
(Federal-Provincial Advisory Committee on Air Quality April 1987).

These values coincide with the Canadian national levels for air quality.

Significant air quality levels and their effects on health and well-being are tabulated in Table 4.6.1.

Table 4.6.1
Selected Air Quality Data for Health Effect Thresholds

Ambient Concentrations		Averaging period	Health Effects	Source Literature
SO_2 μ/m^3	TSP* μ/m^3			
12-114	8-51	1 Year	no association between SO_2 and respiratory illness in children	Melia et al. 1981a and b.
21.6-51.4	high	1 Year	Acute respiratory illness incidence significantly higher in communities with higher levels of SO_2	Love et al, 1981
48	28	1 Year	increased prevalence of cough in children	Dodge, 1983
56-104	53-83	1 Year	SO_2 significant risk factor for serious chest illness before age 2 and for chest illness >3 days in lifetime residents	Schenker et al, 1982
70-80		1 Year	increase in acute respiratory illness and effects on pulmonary function in children	Saric et al, 1981
139-339		1 Year	significant greater decrease in Vital Capacity and Forced Expiratory Volume	Van der Lende et al, 1981
193		24 hour	no adverse effects on bronchitics	Emmerson, 1973
300	present	24 hour	increase in hospitalization	Brasser et al, 1967
400		24 hour	increased hospital admissions for cardiac and respiratory illness	Martin, 1964
500		24 hour	worsening health in bronchitics	Lowther 1958, L. et al, 1970
1000	500-2000	24 hour	increased mortality rates	F-PACAQ, 1987
780-2600		instant	detect taste and odour	Patty, 1963
1000		1 hour	transient effects on pulmonary function in excercising asthmatics	Hackney et al, 1984
<2600		brief	no effects in healthy subjects	Ericsson and Cammer, 1983
<2600		2 hours	possibly minor and reversible transient effects on airway resistance	Stacy et al, 1978
>2600		brief	increase in respiration rate, airway airflow resistance; decrease in tidal volume, forced expiratory flow, nasal-mucocciliary flow rate	Boushey et al, 1984
>14000		brief	increase in tracheo-bronchial clearance	Boushey et al, 1984

*Total Suspended Particulates

4.6.3 Thresholds and Exceedances

Exceedances of significant thresholds for 1986 and 1987 are presented in Table 4.6.2 As the Ministry of Environment monitor represents only the number of exceedances at its location an estimate of the potential number of exceedances in the total zone with this air pollution regime is projected and presented under "Projected Total".

Table 4.6.2

Number of Exceedances of Selected SO_2 Air Quality Levels for 1986 and 1987, and the Projected Maximum Exceedances for the Impingement Zone

Averaging Period	Air Qual. μ/m^3	1986		1987	
		Monitor	Proj. Total	Monitor	Proj. Total
1 hour	2600	78	289	41	126
	900	394	1459	346	1064
	450	876	3248	922	2837
	350	1114	4125	1159	3566
24 hour	360	8	29	3	9
	260	87	322	76	233
	160	132	488	136	418
1 month	350	>1	>6	0	-
	200	>4	>25	>2	>6
	150	>7	>44	>7	>21

Data capture for 1986 and 1987 was respectively 66% and 95% of the potential total of 8760. The actual number of data for 1986 is 5781 and for 1987 it is 8322. These numbers were applied to the % frequencies of table 3.2.2 to calculate the actual number of exceedances at the monitor for each of the air quality thresholds. The Projected Total number of exceedances is based on three assumptions:

1) The mill is in operation for 24-hours each day at typical production rates.

2) "0" readings result from a dispersion of ambient SO_2 in directions other than the direction in which the monitor is located.

3) The dispersion characteristics of the belt around the source on the average are similar to those towards the monitor.

Each of these assumptions may introduce significant errors in the estimates. The Projected Total number of exceedances is an estimate of the total number of exceedances that will occur throughout the same belt of impingement. This is distinct from the frequency of exceedance represented by the measurements from the stationary monitor, which indicate the chance to encounter an exceedance in one specific location. The estimates do not include exceedances in adjacent impingement belts and in this respect underestimate the total number of exceedances. Assumption "2)" implies the maximum limit of the number of exceedances under the current production regime. This limit is not likely to be met in actuality. A comparison of tables 4.6.1 and 4.6.2 readily reveals that the significant thresholds have been exceeded repeatedly. Even 1-hour exposures to 2600 μ/m^3 of SO_2 are generally considered serious and effects may occur even to the most tolerant members of the population. This level was exceeded 78 times at the monitor, and it is likely exceeded more frequently over the whole of the affected area. For 1986 and 1987 the highest 1 hour means for each month ranged from 2000 to 9400 μ/m^3, and averaged 5000 μ/m^3. Short

exposures of as low as 1000 μ/m^3 will cause stress for more vulnerable members of the population. This level was exceeded frequently, and is likely to occur commonly in various parts of the area influenced by the emissions from the mill. Brief exposures to 300 μ/m^3 is not likely to effect the majority of the people. However mean exposures of 24 hours to this level have been associated with increases in hospitalization rates. Air quality values near these levels were exceeded significantly. Monthly 24-hour averages ranged from 325 μ/m^3 to 1900 μ/m^3 in the period 1986/87. These levels are well in excess of the long-term (1 Year) thresholds and also exceed many of the 24-hour thresholds. Sustained exposures to ambient SO_2 levels in excess of 100 μ/m^3 may have adverse effects on most members of a population. Levels above 60 μ/m^3 may affect small children and sensitive members of the population. Data to confirm a health risk from prolonged exposure to the ambient air of the Port Alice area is incomplete. However it appears that the threshold values have been well exceeded.

CHAPTER FIVE
CONCLUSIONS

SO_2 emissions have significantly impacted on the environment near Port Alice. Impacts on air quality, soils, vegetation and health have been documented in this preliminary assessment. Water quality, epidemiological studies and the welfare of the fauna were outside the scope of this assessment. Interrelationships between the atmosphere, soils, vegetation, and health must be fully understood before a comprehensive assessment of the effects of the emissions on the environment is possible.

Specific findings of environmental effects from emissions of SO_2 on air quality, soils, vegetation and health are summarized as follows:

5.1 Atmospheric Emissions

Information on atmospheric emissions permits an estimate of annual sulphur dioxide emissions. SO_2 emissions have been estimated at approximately 4100 kg/day in 1981 for a total annual emission of 1.1 million kg SO_2, at 4600 kg SO_2 day in 1982 for a low annual total of 0.8 million kg SO_2, and at a high of 21000 kg SO_2 per day in 1986 for annual emission of 6.8 million kg SO_2.

An increasing trend in annual emissions is evident.

5.2 Air Quality

A deteriorating air quality trend from 1981 to 1985 is

evident. The available data are likely to underestimate the actual concentrations of SO_2. It appears that this trend is continued in 1986 and 1987.

Temporal and spatial air quality gradents in the Port Alice area cannot be adequately assessed due to insufficient monitoring and a lack of meteorological information.

Ambient air quality monitors in Port Alice and Rumble Beach are unlikely to represent actual maximum concentrations of SO_2 in the region. Even so, monitored data indicate that the ambient SO_2 problem is acute in the Port Alice area.

5.3 Bio-climate

Conditions for active respiration and gas exchange in conifers may occur throughout the year. No distinct dormant season can be defined. Some drought stress may occur periodically. The worst stress occurred in 1958, while 1985 also represents a dry year. It is not likely that drought accounts for the death and decline of the forests near Port Alice.

High precipitation for 9 months from September to May, may limit the impacts to a more restricted area. Maximum impacts are likely to occur in June, July, or August over a wider area.

5.4 Soils

Clear trends of increases in total sulphur, and decreases in exchangeable calcium, magnesium, percent base saturation, and

soil pH were observed with decreasing distance from the mill. Sulphate sulphur decreases with distance were noted for subsurface horizons. A trend of decrease of extractable copper with distance appeared to exist but was not apparent for extractable zinc or exchangeable aluminum, two additional constituents expected to increase with acidity. The trend of decreasing total nitrogen in surface soils with decreasing distance may indicate reduced mineralization due to reduced microbial activity.

The expected negative relationship between soil pH and soil sulphur, and between soil sulphur and base saturation percent were observed. A negative relationship between pH and exchangeable aluminum was also observed. Similarly, the expected positive relationships between pH and base saturation and exchangeable calcium, for example, were noted. These relationships support the observations of trends with distance from the mill, and together allow the conclusion that mill sulphur dioxide emissions and sulphur deposition are increasing soil acidity and decreasing basic plant nutrient elements in soils in the area.

Total sulphur in Port Alice soils is high, when compared to values for soils generally, as well as to soils in other areas of B.C., some themselves expected to be high due to industrial emissions. Similarly, exchangeable aluminum appeared to be on the high end of the expected range, and positive crop response to liming might be expected. Extractable copper and zinc, as indicator-constituents more soluble due to acidification, were well within ranges measured for other soils in B.C.

5.5 Vegetation

Visible injury symptoms are widespread and consistent with sulphur dioxide injury symptoms documented in the literature.

Total sulphur content of leaves is higher than background ("clean air") levels in proportion to dosages (duration and concentration) of sulphur dioxide received. Wind direction, age of foliage and distance from source are the major factors determining variation in tissue sulphur.

Suggested species sensitivities to sulphur dioxide exposures are consistent with those reported in the literature.

Atmospheric concentrations since 1981 are at levels reported to cause acute and chronic injury to vegetation[24].

In spite of a dramatic reduction in air emissions between 1978 and 1980 due to installation of pollution control equipment, in 1981 ambient mean-annual hourly concentrations were estimated to be 107 $\mu g/m^3$, which is well in excess of threshold values for vegetation injury. Between 1981 and 1985 the mean annual concentrations increased by approximately 21 $\mu g/m^3$ annually. Conditions in 1986 and 1987 are a continuation of the increasing trend.

It is likely that atmospheric concentrations rose from 1918 levels, in the same order of magnitude as 1982, to 1978(-80) levels considerably greater than the 1982 levels.

The findings reported as a result of a preliminary inspection are based on limited study and data. To establish full

statistical confidence for these findings a more substantial study program is required.

In summary the vegetation has been impacted by atmospheric sulphur dioxide pollution by:

- reduction of species survival and vegetation diversity

- visible injury and defoliation thus inhibiting productivity

- invisible injury/effects, reflected in elevated levels of total sulphur in foliage, thus causing reduced growth and vigor of the plants as well as altering the mineral cycles of the ecosystems

- increased susceptability to pathogens as a result of tissue injuries and surface wounds offering opportunities for infection which affect resource values for forestry, wildlife and recreation and, over the longer term, ecosystem balances. An evaluation of the loss of resource values and the magnitude of impacts appears in order.

5.6 Public Health

A significant risk exists for all members of the population. Short term exposures of sufficient ambient concentrations to cause acute health problems may be encountered. Longer term exposures are of sufficient intensities that a risk of increased disease occurrence, hospitalization and, possibly, increase in mortality can not be ruled out. The area may present a high risk for sensitive groups of the population, including young children and people with respiratory problems.

CHAPTER SIX
REQUIREMENTS FOR COMPREHENSIVE IMPACT ASSESSMENT

As it is evident from the preliminary information that the atmosphere, vegetation and soil components of the environment are being impacted by SO_2 emissions from the Port Alice sulphite pulpmill, a full assessment of impacts must be based on a tracking of sulphur and its effects through the natural environment. When the pathway and fate of the sulphur is fully understood a comprehensive assessment of the impacts is possible.

It is recommended that effects of emissions on water quality, health of the population, and wildlife be investigated as these were not considered in this report.

The findings of this report and of the recommended work are part of the technical input needed to define objectives and strategies for environmental management. Weaknesses, gaps, and uncertainties in the existing data bases, and gaps in the knowledge regarding the effects of the pollutants on the land-based resources make it necessary to undertake further work to complete a comprehensive assessment of impacts and to develop an effective appreciation of the tolerances of the environment. The following recommendations for further action aim to fill the shortcomings of the available information.

RECOMMENDATIONS

6.1 Atmospheric Emissions

Accurate emission information is required to project and

and assess the spatial and temporal distribution of regional air pollution and to determine its chemical constituents. Subsequently the sensitivity of the land to air pollution can be determined and the damage that may result can be assessed. The nature of the emissions also is an indication of the proper technical functioning of the pulpmill.

The following actions are therefore recommended:

1. To determine pollutant emission characteristics, perform a comprehensive emission inventory of all pollutants.

2. To obtain accurate information on the emissions from the major sources, initiate continuous monitoring of the Acid Plant and Recovery Furnace/Blow Gas Absorption stacks.

6.2 Air Quality

Modelling of the diffusion and dispersion of atmospheric pollutants from the Port Alice pulpmill is necessary to identify the distribution of air pollutants in the Port Alice area and to determine the relationship between ambient air quality observations at the monitored sites and the local air quality. Representative emissions and meteorological data are required for plume dispersion modelling. Dispersion model output is to be calibrated using appropriate ambient air quality observations. The following actions are recommended to complete a more comprehensive assessment of local air quality:

1. To generate meteorological data essential to model ambient air quality of the area, establishment and

operation of a meteorological station for at least 12 months is required.

2. To yield accurate air quality data, to calibrate modelling results, to monitor air quality, and to identify peak concentrations, SO_2 monitoring stations must be established and/or upgraded and maintained.

3. To assess the effects of the pulpmill emissions on acid rain and sulphur deposition, precipitation chemistry and acid deposition (acid rain) are to be determined.

6.3 Soils

Adverse impacts on soil quality will result in deteriorating water quality, and possibly decline of vegetation, which in turn may cause increased erosion, slope failures, and decreased usefulness of the land for wildlife and tourism. To resolve some of the uncertainties associated with this preliminary investigation, to aid the assessment of environmental impact, to determine the specific sensitivity of the soils to the atmospheric emissions, and to monitor the effectiveness of air management measures towards improving environmental conditions the following actions are recommended:

1. To provide a basis for mapping the patterns of impact on soil and vegetation, and to assess soil sensitivity, a map of the land base needs to be prepared at an appropriate scale.

2. To determine specific dose-response relationships and to monitor the quality of the soil and its minerals, soil characteristics need to be monitored on selected "benchmark" sites.

3. To investigate the feasibility of soil improvements, liming forest response experiments are to be conducted.

4. To aid in the determination of environmental sensitivity, the effect of acid deposition on soils needs to be modelled.

6.4 Vegetation

The health of vegetation is an indication of the state of health of the environment. The demise of vegetation will lead to large scale environmental problems including deterioration in water quality, slope failures, wildlife habitat deterioration, and soil erosion. In the coastal forests the role of the vegetation in preventing site degradation and reducing metal toxicity is critical. To determine the impacts that have occurred on the environment and the sensitivities of the vegetation to the air pollutants, and to monitor the ongoing health of the vegetation the following actions are recommended:

1. To determine the present state of the vegetation, the relationship between air quality and vegetation needs to be further investigated and the projected impacts on forest growth and health, tree species distribution, community composition for major ecosystems, distribution of bryophytes and lichens,

and tissue sulphur content need to be mapped at an appropriate scale.

2. To monitor the health and functioning of the ecosystems the sulphur mineral cycle, forest growth and health, and species diversity needs to be determined on selected "benchmark" sites as long as any effects are evident.

3. To further remove uncertainties associated with the causes of the forest death it is necessary to determine the temporal patterns of forest decline and death by means of tree ring analysis.

6.5 Health

The usefulness of an area, regardless of its resource potential, may be impaired if the environment is not conducive to human health. The personal and socio-economic benefits of resources may be reduced where costs of public health are high due to environmental pollution. To ensure that public health is adequately assessed the following actions are recommended:

1. To ensure accurate detection and assessment of health risk from instantaneous, periodic and chronic exposures, it is necessary to continue the compilation of suitable air quality data.

2. To determine the frequency and severity of risk to health for the people of the Port Alice area, a comparison of the patterns of injurious air

qualities, in time and space, and the patterns of daily movement of the people is to be made, and the risk to each of the groups of the population, such as children and other sensitive segments of the population, short- and long-term mill workers, domestic residents, and any other relevant group of the population, is to be assessed.

3. To determine impacts on public health, epidemiological studies of population groups need to be completed.

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Appendix 1

Soils

A.1.1 Selected Soil Chemical Data

A.1.1 Selected Soil Chemical Data

Site	Horiz.No	Exp.Ind.	Distance	P-Kel	SO4-S
1	1.00	2.00	0.65	17.00	27.00
1	2.00	2.00	0.65	6.00	203.00
1	3.00	2.00	0.65	4.00	223.00
2	1.00	4.00	4.65	19.00	24.00
2	2.00	4.00	4.65	8.00	53.00
2	3.00	4.00	4.65	3.00	56.00
3	1.00	3.00	1.85	16.00	55.00
3	2.00	3.00	1.85	3.00	124.00
3	3.00	3.00	1.85	2.00	173.00
4	1.00	1.00	0.30	20.00	44.00
4	2.00	1.00	0.30	11.00	103.00
4	3.00	1.00	0.30	3.00	127.00
6	1.00	5.00	5.85	44.00	60.00
6	2.00	5.00	5.85	3.00	27.00
6	3.00	5.00	5.85	5.00	27.00
7	1.00	6.00	25.00	11.00	26.00
7	2.00	6.00	25.00	0.00	49.00
7	3.00	6.00	25.00	0.00	33.00
8	1.00	7.00	65.00	24.00	23.00
8	2.00	7.00	65.00	2.00	11.00
8	3.00	7.00	65.00	0.00	19.00

Horizon 1 = LFH

Horizon 2 = Bf_1 or Ahe

Horizon 3 = Bf_1 or Bf_2

see Table 3.4.1

Site	Horiz.No	Exp.Ind	Distance	Extrc-Zn	Exch-Al	L.R.6.0	L.R.5.4
1	1.00	2.00	0.65	6.87	210.37		18.40
1	2.00	2.00	0.65	0.21	44.37	6.40	
1	3.00	2.00	0.65	0.21	43.93	13.70	
2	1.00	4.00	4.65	15.79	161.78		25.40
2	2.00	4.00	4.65	2.92	165.91		21.90
2	3.00	4.00	4.65	0.83	55.70	16.40	
3	1.00	3.00	1.85	2.56	666.52		19.60
3	2.00	3.00	1.85	0.83	156.77		18.40
3	3.00	3.00	1.85	0.21	100.53	19.30	
4	1.00	1.00	0.30	5.17	197.40		19.60
4	2.00	1.00	0.30	0.63	71.07	17.80	
4	3.00	1.00	0.30	0.00	22.55	11.30	
6	1.00	5.00	5.85	6.24	154.43		20.70
6	2.00	5.00	5.85	0.10	0.21		
6	3.00	5.00	5.85	0.00	0.00		
7	1.00	6.00	25.00	9.15	217.11		21.90
7	2.00	6.00	25.00	0.00	23.04	12.50	
7	3.00	6.00	25.00	0.10	7.31	11.30	
8	1.00	7.00	65.00	10.13			24.20
8	2.00	7.00	65.00	0.30	98.33	17.80	
8	3.00	7.00	65.00	0.51	19.28	12.50	

Site	Horiz.No	Exp.Ind	Distance	Extrc-Fe	Total-S	Extrc-Cu
1	1.00	2.00	0.65	1497.25	0.21	3.43
1	2.00	2.00	0.65	126.91	0.17	1.05
1	3.00	2.00	0.65	90.59	0.19	0.74
2	1.00	4.00	4.65	1013.31	0.10	2.49
2	2.00	4.00	4.65	2695.30	0.08	0.63
2	3.00	4.00	4.65	186.52	0.07	0.62
3	1.00	3.00	1.85	2311.93	0.15	2.66
3	2.00	3.00	1.85	1153.40	0.10	2.29
3	3.00	3.00	1.85	353.53	0.14	1.57
4	1.00	1.00	0.30	1217.61	0.29	3.12
4	2.00	1.00	0.30	457.97	0.10	14.68
4	3.00	1.00	0.30	85.60	0.12	0.31
6	1.00	5.00	5.85	744.54	0.17	0.63
6	2.00	5.00	5.85	93.76	0.04	0.00
6	3.00	5.00	5.85	128.09	0.03	0.41
7	1.00	6.00	25.00	1444.23	0.08	2.63
7	2.00	6.00	25.00	191.97	0.04	1.34
7	3.00	6.00	25.00	98.43	0.07	1.36
8	1.00	7.00	65.00	113.07	0.10	0.21
8	2.00	7.00	65.00	183.46	0.00	0.10
8	3.00	7.00	65.00	42.04	0.01	0.31

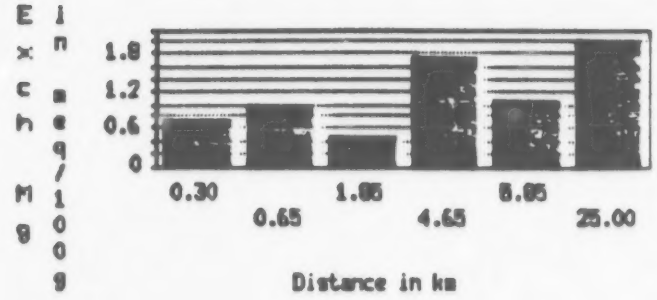
Site	Horiz.No	Exp.Ind	Distance	Base-Sat	Total-N	Kel-SO4-
1	1.00	2.00	0.65	3.20	1.14	27.00
1	2.00	2.00	0.65	0.90	0.19	203.00
1	3.00	2.00	0.65	0.80	0.19	223.00
2	1.00	4.00	4.65	4.10	1.18	24.00
2	2.00	4.00	4.65		0.52	53.00
2	3.00	4.00	4.65		0.22	56.00
3	1.00	3.00	1.85	1.50	0.96	55.00
3	2.00	3.00	1.85	0.70	0.39	124.00
3	3.00	3.00	1.85	0.70	0.27	173.00
4	1.00	1.00	0.30	3.20	1.51	44.00
4	2.00	1.00	0.30		0.25	103.00
4	3.00	1.00	0.30		0.20	127.00
6	1.00	5.00	5.85	7.90	1.23	60.00
6	2.00	5.00	5.85	22.00	0.20	27.00
6	3.00	5.00	5.85	39.20	0.21	27.00
7	1.00	6.00	25.00	7.00	0.46	26.00
7	2.00	6.00	25.00	1.10	0.11	49.00
7	3.00	6.00	25.00	0.50	0.16	33.00
8	1.00	7.00	65.00		1.01	23.00
8	2.00	7.00	65.00		0.07	11.00
8	3.00	7.00	65.00		0.06	19.00

Site	Horiz.No	Exp.Ind	Distance	pH-H20	pH-CaCl2	Exch-Ca	Exch-Mg
1	1.00	2.00	0.65	3.30	2.63	2.53	1.00
1	2.00	2.00	0.65	4.44	4.24	0.19	0.06
1	3.00	2.00	0.65	4.47	4.33	0.13	0.04
2	1.00	4.00	4.65	3.37	2.73	2.74	1.72
2	2.00	4.00	4.65	3.52			
2	3.00	4.00	4.65	4.41	4.26	0.04	0.05
3	1.00	3.00	1.85	3.66	2.92	0.51	0.47
3	2.00	3.00	1.85	4.37	3.75	0.10	0.12
3	3.00	3.00	1.85	4.24	4.10	0.08	0.08
4	1.00	1.00	0.30	3.30	2.64	2.16	0.74
4	2.00	1.00	0.30	4.40	4.22	0.15	0.05
4	3.00	1.00	0.30	4.56	4.51	0.17	0.18
6	1.00	5.00	5.85	4.00	3.36	4.71	1.08
6	2.00	5.00	5.85	5.80	5.44	6.41	0.45
6	3.00	5.00	5.85	6.38	6.09	13.14	0.86
7	1.00	6.00	25.00	3.99	3.22	4.24	2.03
7	2.00	6.00	25.00	4.56	4.41	0.10	0.07
7	3.00	6.00	25.00	4.80	4.67	0.04	0.06
8	1.00	7.00	65.00				
8	2.00	7.00	65.00	3.85	3.36	0.06	0.06
8	3.00	7.00	65.00	4.73	4.42	0.05	0.02

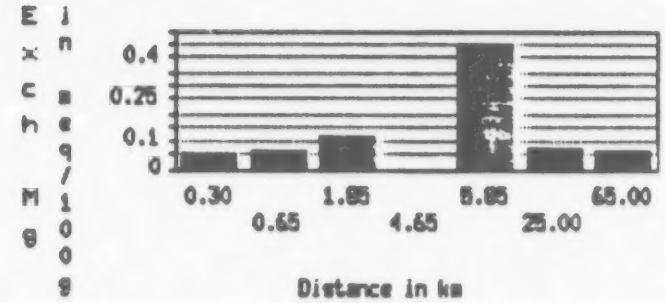
A.1.2 Figures

Figure A.1.1 Exchangeable Magnesium Levels at Distances from Mill

a) Horizon one



b) Horiz. two



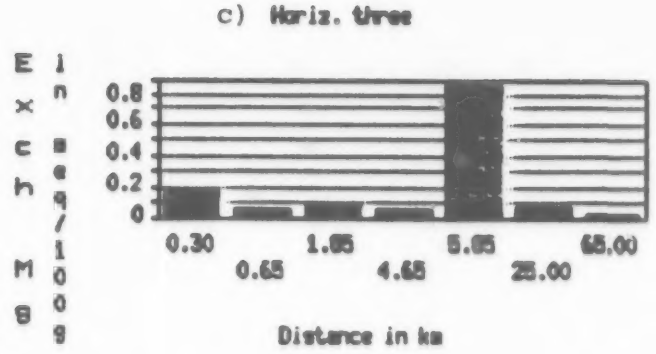
Horizon 1 = LFH

Horizon 2 = Bf_1 or Ahe

Horizon 3 = Bf_1 or Bf_2

see Table 3.4.1

Figure A.1.1 Exchangeable Magnesium Levels at Distances from Mill



Horizon 1 = LFH

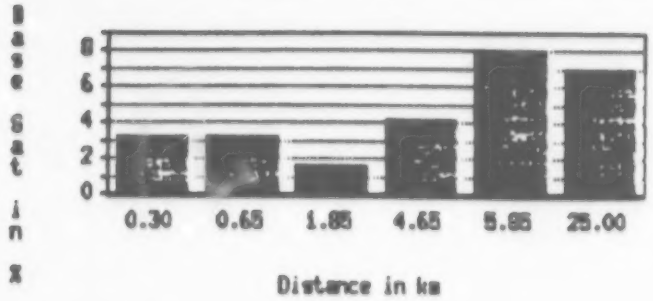
Horizon 2 = Bf_1 or Ahe

Horizon 3 = Bf_1 or Bf_2

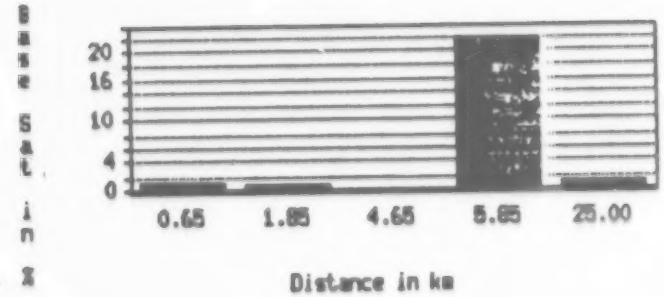
see Table 3.4.1

Figure A.1.2 Base Saturation Levels at Distances from Mill

a) Horiz. one

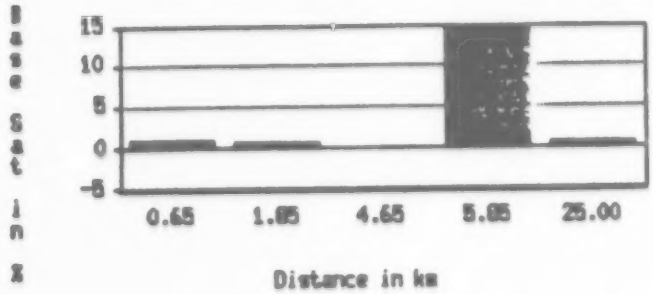


b) Horiz. two



c) Horiz. three

Base Sat 39.20 % at 5.85 km is off graph



Horizon 1 = LFH

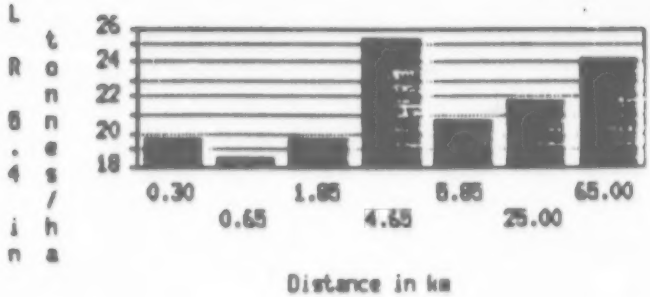
Horizon 2 = Bf_1 or Ahe

Horizon 3 = Bf_1 or Bf_2

see Table 3.4.1

Figure A.1.3 Liming Requirement to pH 5.4 at Distances from Mill

a) Horiz. one



Horizon 1 = LFH

Horizon 2 = Bf_1 or Ahe

Horizon 3 = Bf_1 or Bf_2

see Table 3.4.1

PORT ALICE SO-2 STUDY

b) Horiz. two

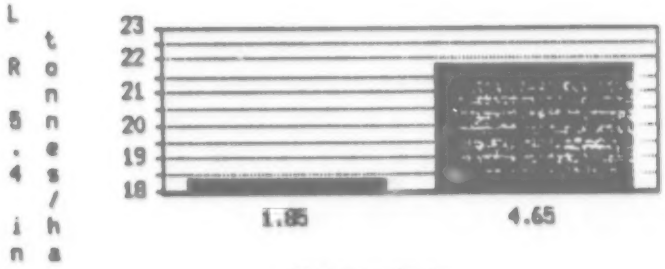
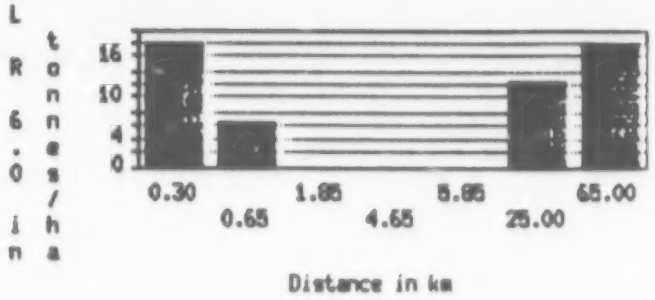


Figure A.1.4 Liming Requirement to pH = 6.0 at Distances from Mill

a) Horiz. two



Horizon 1 = LFH

Horizon 2 = Bf_1 or Ahe

Horizon 3 = Bf_1 or Bf_2

see Table 3.4.1

PORT ALICE SO-2 STUDY

b) Horiz. three

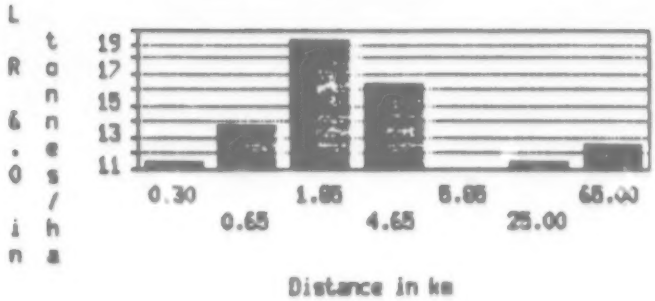
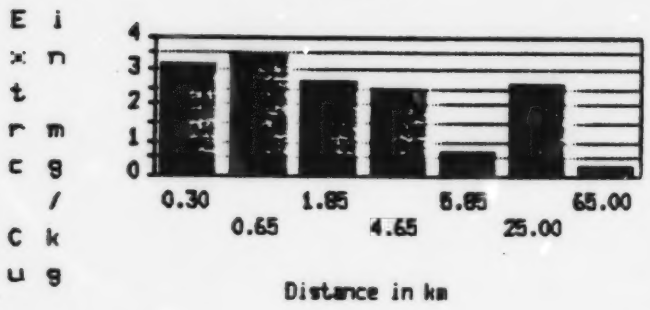
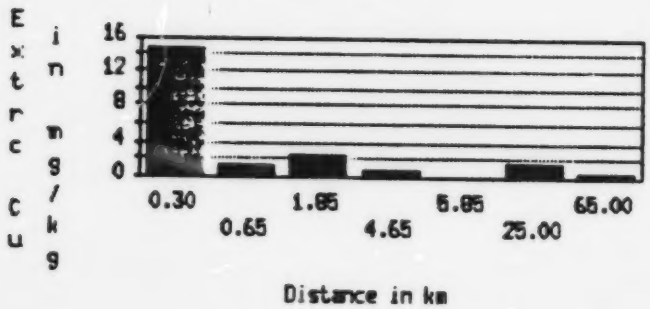


Figure A.1.5 Toxic Metal Concentrations at Distances from Mill: Copper

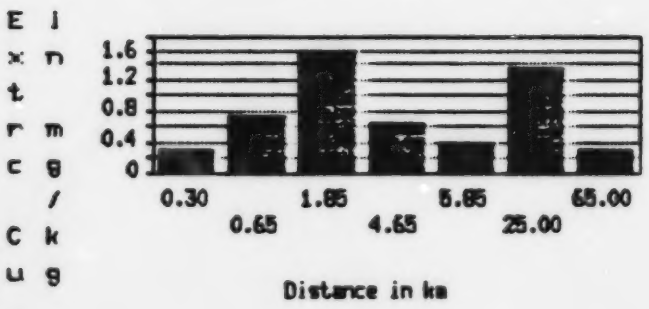
a) Horiz. one



b) Horiz. two



c) Horiz. three



Horizon 1 = LFH

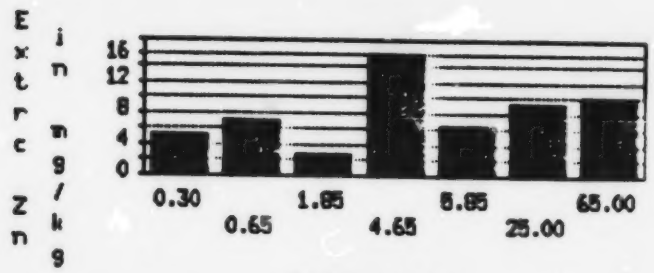
Horizon 2 = Bf_1 or Ahe

Horizon 3 = Bf_1 or Bf_2

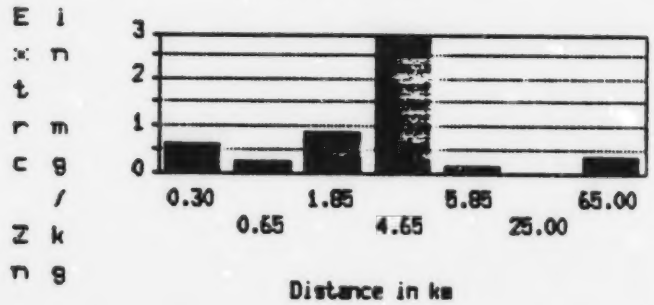
see Table 3.4.1

Figure A.1.6 Toxic Metal Concentrations at Distances from Mill: Zinc

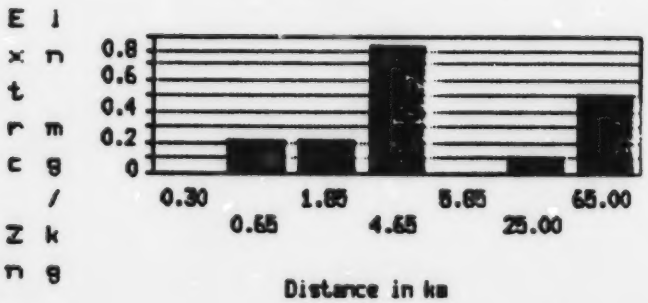
a) Horiz. one



b) Horiz. two



c) Horiz. three



Horizon 1 = LFH

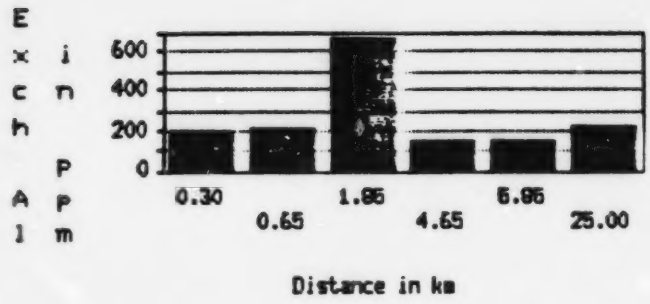
Horizon 2 = Bf_1 or Ahe

Horizon 3 = Bf_1 or Bf_2

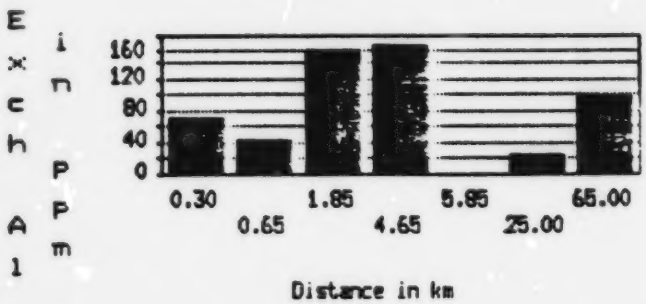
see Table 3.4.1

Figure A.1.7 Toxic Metal Concentrations at Distances from Mill: Aluminum

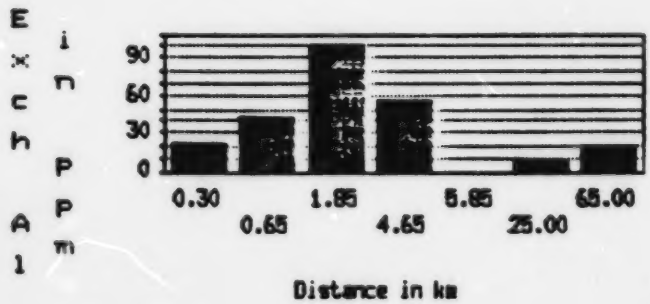
a) Horiz. one



b) Horiz. two



c) Horiz. three



Horizon 1 = LFH

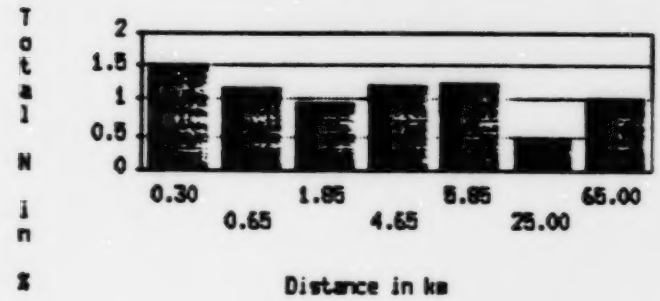
Horizon 2 = Bf_1 or Ahe

Horizon 3 = Bf_1 or Bf_2

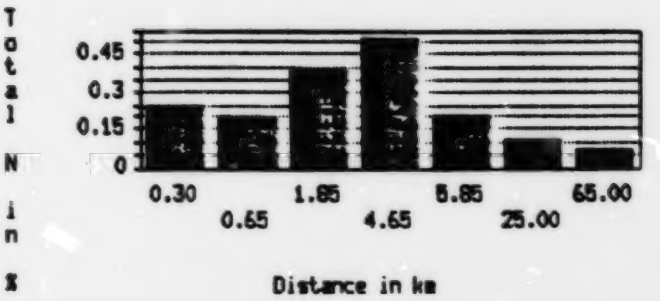
see Table 3.4.1

Figure A.1.8 Nitrogen Levels at Distances from Mill

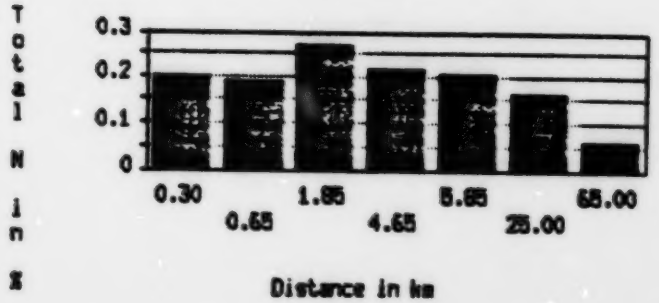
a) Horiz. one



b) Horiz. two



c) Horiz. three



Horizon 1 = LFH

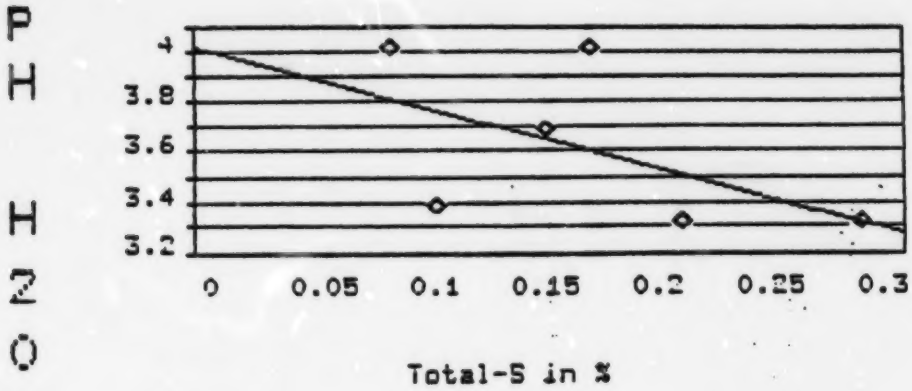
Horizon 2 = Bf_1 or Ahe

Horizon 3 = Bf_1 or Bf_2

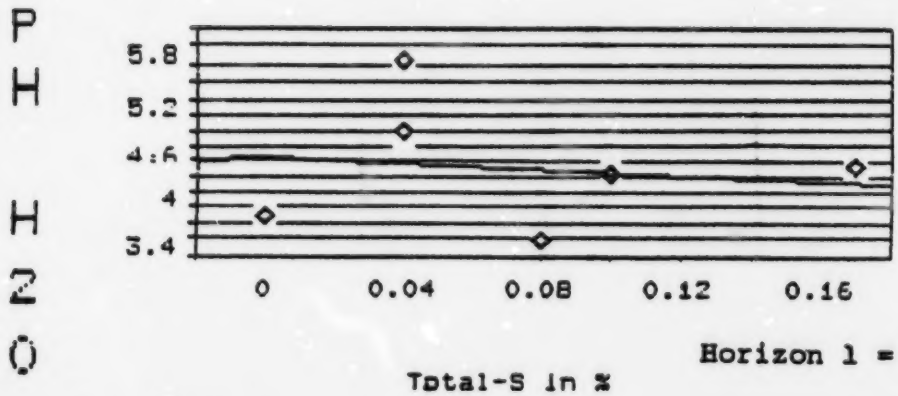
see Table 3.4.1

Figure A.1.9 Soil Acidity and Total Sulphur

a) Horiz. 1



b) Horiz. 2

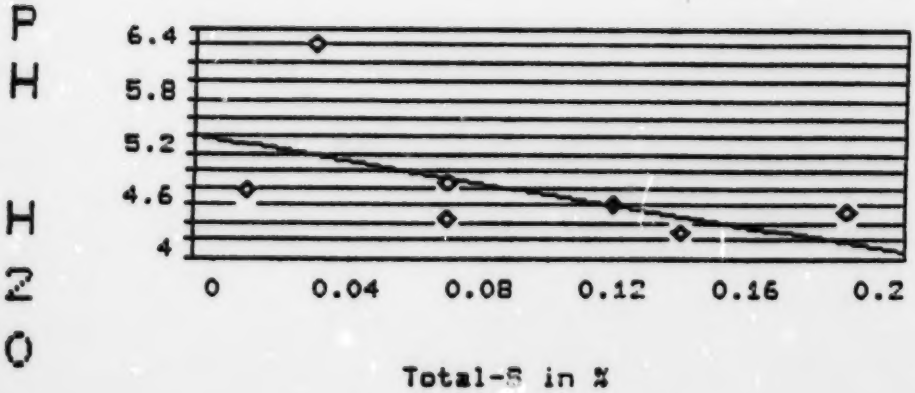


Horizon 1 = LFH

Horizon 2 = Bf_1 or Ahe

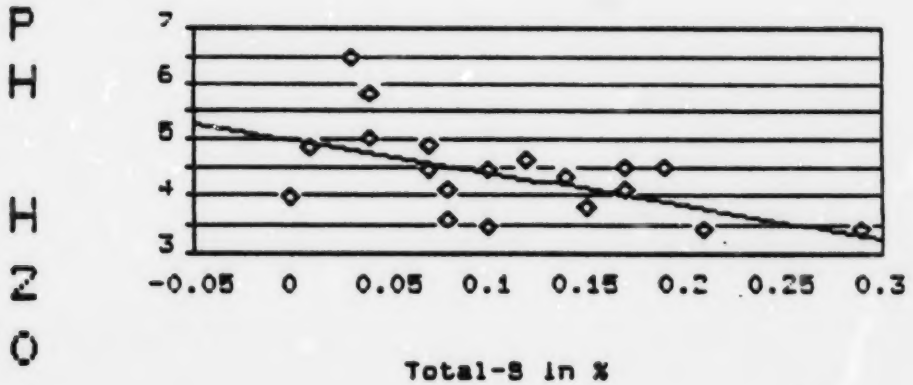
c) Horiz. 3

Horizon 3 = Bf_1 or Bf_2



see Table 3.4.1

d) Horiz. 1,2,3



Horizon 1 = LFH

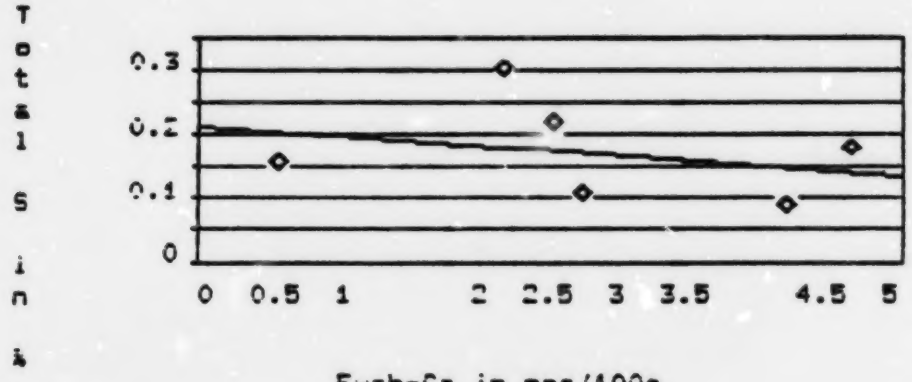
Horizon 2 = Bf_1 or Ahe

Horizon 3 = Bf_1 or Bf_2

see Table 3.4.1

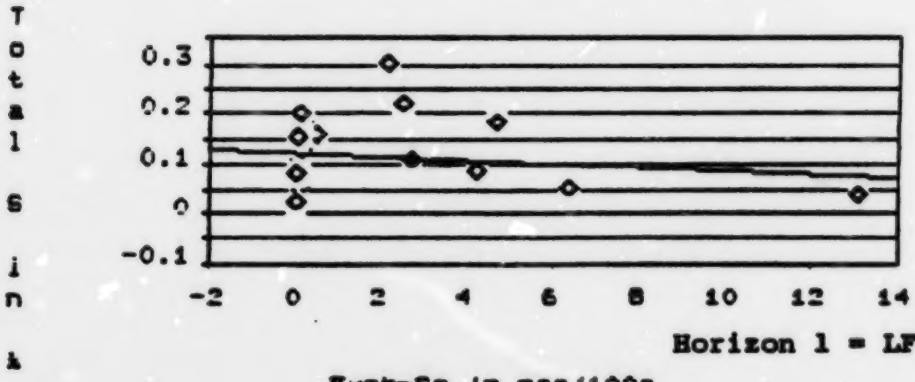
Figure A.1.10 Total Sulphur and Exchangeable Calcium Levels

a) Horiz. 1



PORT ALICE SO-2 STUDY

b) Horiz. 1,2,3



Horizon 1 = LFH

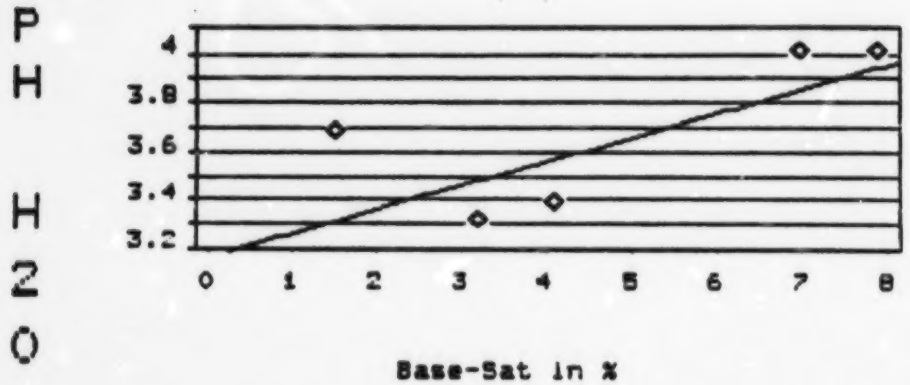
Horizon 2 = Bf_1 or Ahe

Horizon 3 = Bf_1 or Bf_2

see Table 3.4.1

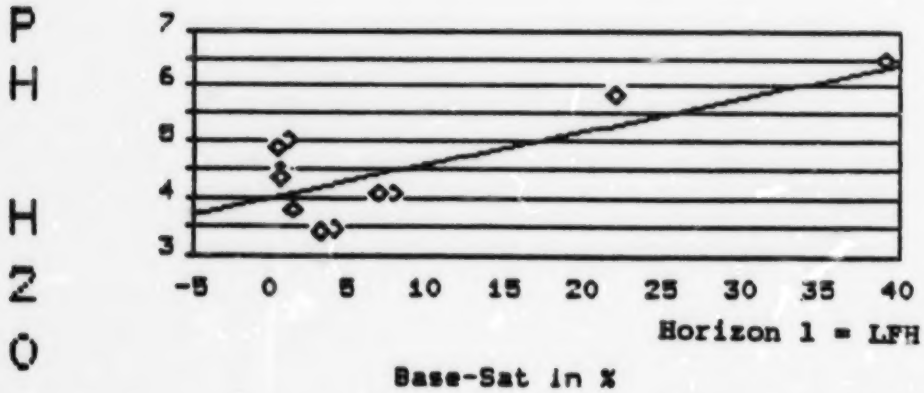
Figure A.1.11 Soil Acidity (H_2O) and Base Saturation

a) Horiz. 1



PORT ALICE SO-2 STUDY

b) Horiz, 1,2,3



Horizon 1 = LFH

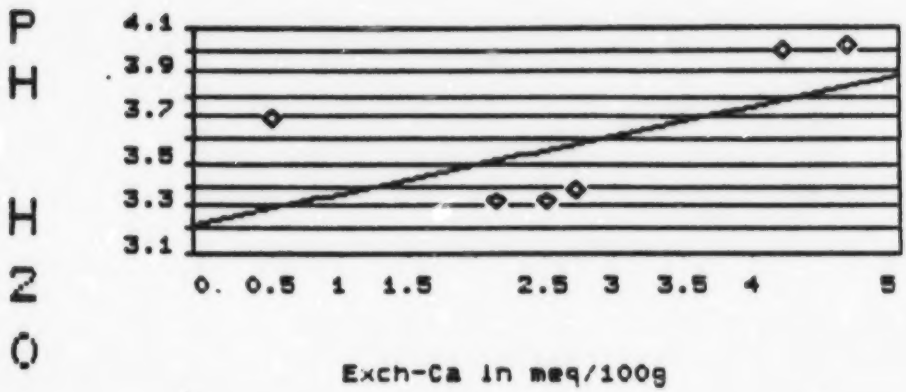
Horizon 2 = Bf_1 or Ahe

Horizon 3 = Bf_1 or Bf_2

see Table 3.4.1

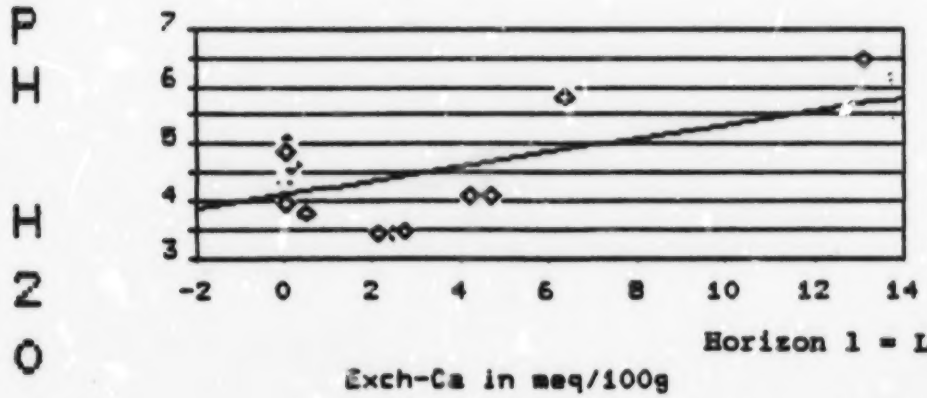
Figure A.1.12 Soil Acidity (H_2O) and Exchangeable Calcium

a) Horiz. 1



PORT ALICE 50-2 STUDY

b) Horiz. 1,2,3



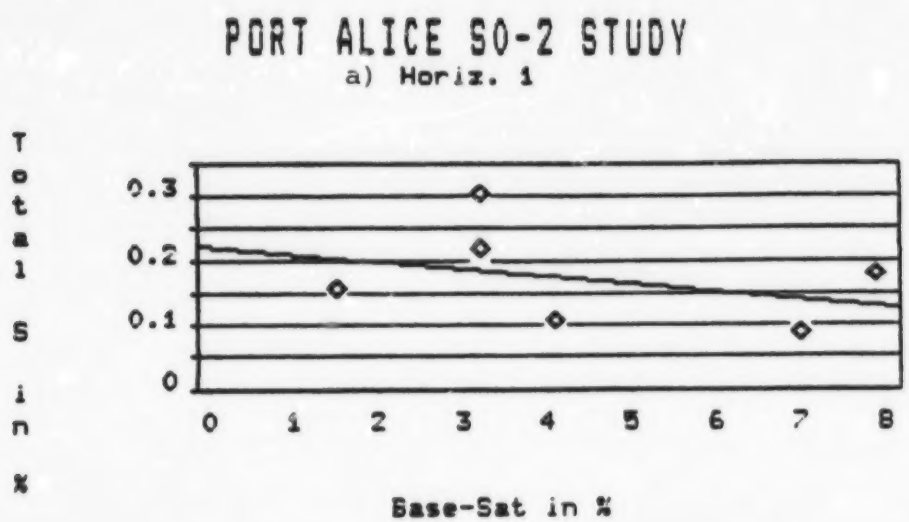
Horizon 1 = LFH

Horizon 2 = Bf_1 or Ahe

Horizon 3 = Bf_1 or Bf_2

see Table 3.4.1

Figure A.1.13 Total Sulphur and Base Saturation



Horizon 1 = LFH

Horizon 2 = Bf_1 or Ahe

Horizon 3 = Bf_1 or Bf_2

see Table 3.4.1

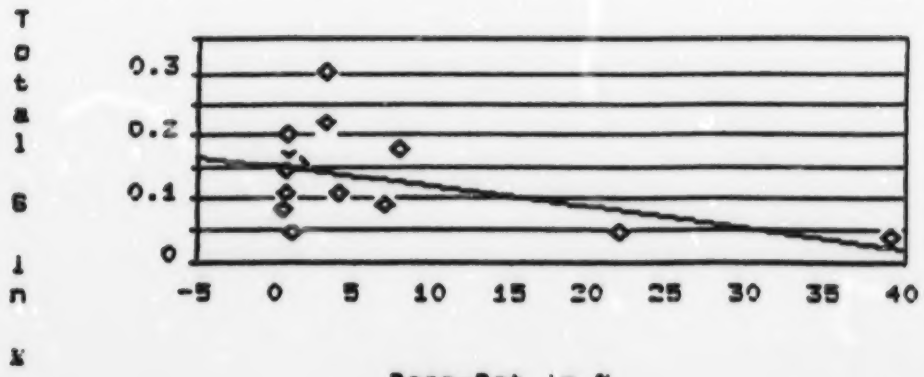
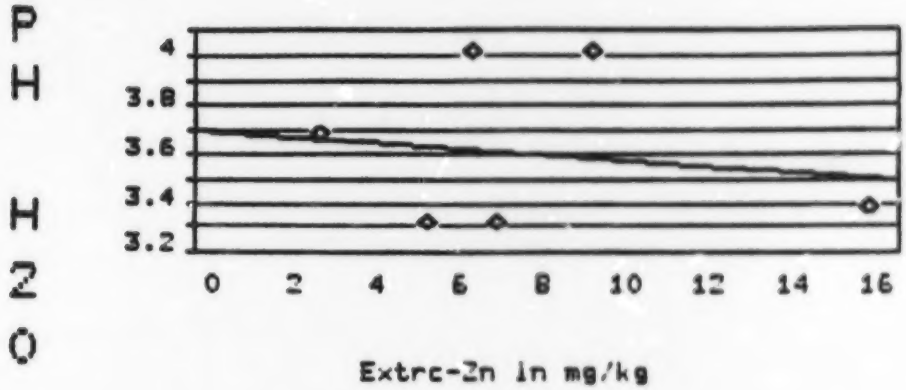


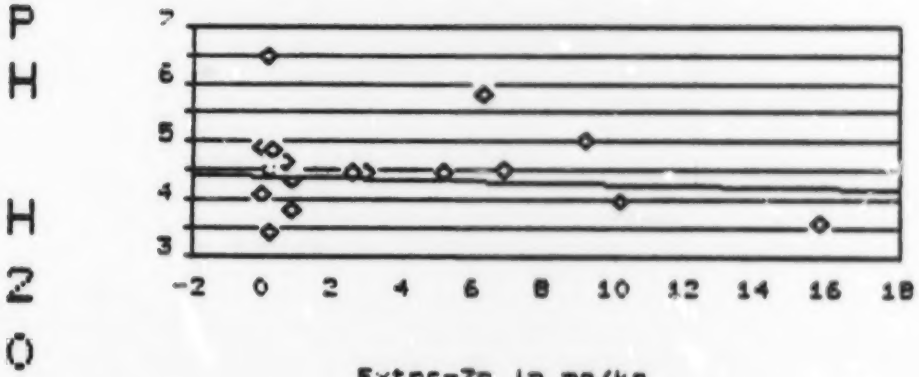
Figure A.1.14 Soil Acidity and Toxic Metal Concentrations: Zinc

a) Horiz. 1



PORT ALICE SO-2 STUDY

b) Horiz. 1,2,3



Horizon 1 = LFH

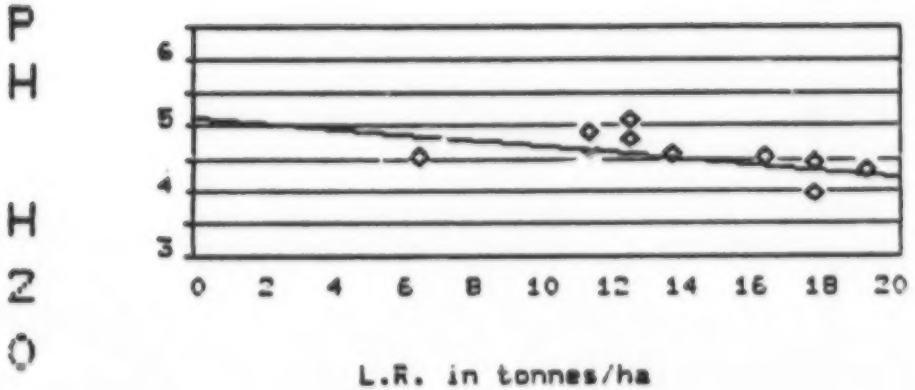
Horizon 2 = Bf_1 or Ahe

Horizon 3 = Bf_1 or Bf_2

see Table 3.4.1

Figure A.1.15 Soil Acidity (H_2O) and Liming Requirement (pH=6.0)

a) Horiz. 1,2,3



Horizon 1 = LFH

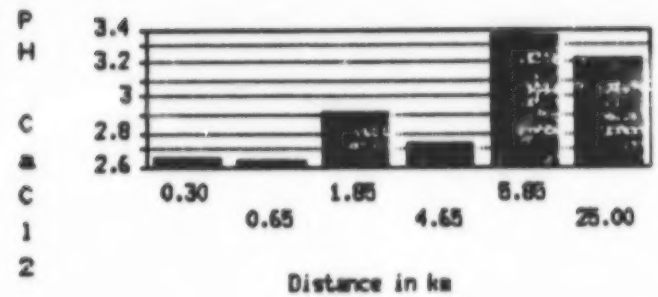
Horizon 2 = Bf_1 or Ahe

Horizon 3 = Bf_1 or Bf_2

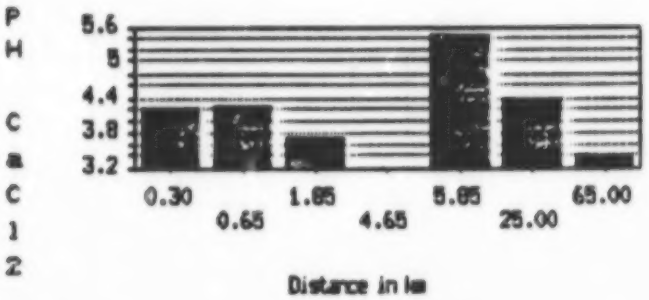
see Table 3.4.1

Figure A.1.16 Soil Acidity ($CaCl_2$) at Distances from Mill

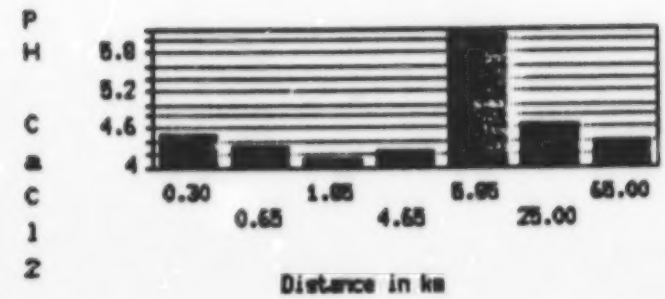
a) Horizon one



b) Horiz. two



c) Horiz. three



Horizon 1 = LFH

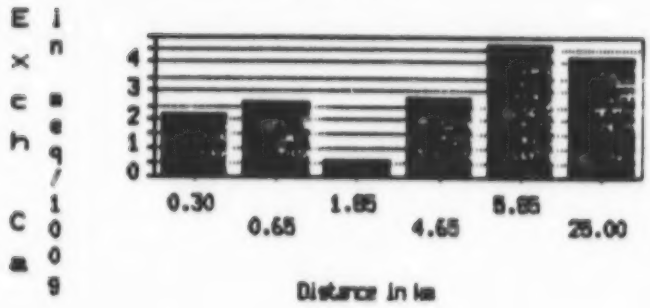
Horizon 2 = Bf_1 or Ahe

Horizon 3 = Bf_1 or Bf_2

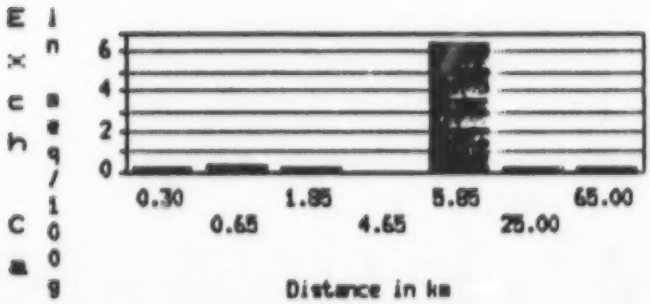
see Table 3.4.1

Figure A.1.17 Exchangeable Calcium Levels at Distances from Mill

a) Horizon one

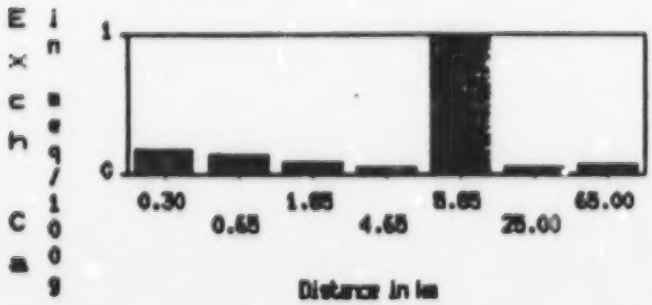


b) Horiz. two



c) Horiz. three

Ca of 13.14 at 5.85 km is off graph



Horizon 1 = LFH

Horizon 2 = Bf_1 or Ahe

Horizon 3 = Bf_1 or Bf_2

see Table 3.4.1

Appendix 2

Vegetation

A.2.1 Species List

Appendix 2 Vegetation

A.2.1 SPECIES LIST

Nomenclature follows Roy L. Taylor and B. MacBryde (1977)[21] for al vascular plants. Mosses are named according to Crumm et al. 1973. Lichens are named according to Hale and Culberson 1970. Forest pests use the terminology in use with B.C. Ministry of Forests and Canadian Forestry Service.

TABLE 10 - SPECIES LIST

COMMON NAME	SYMBOL NAME OR ABBR.	BOTANICAL
Trees:		
amabilis fir	amF	*Abies amabilis*
bitter cherry	Prun ema.	*Prunus emarginata*
coast Douglas-fir	cD	*Pseudotsuga menziesii*
maple	Acer	*Acer*
western hemlock	wH	*Tsuga heterophylla*
western red cedar	wC	*Thuja plicata*
western white pine	wP	*Pinus monticola*
western yew	wY	*Taxus brevifolia*
red alder	rAl	*Alnus rubra*
shorepine	sP	*Pinus contorta var. contorta*
Sitka spruce	sS	*Picea sitchensis*
Shrubs:		
American red elder	arE	*Sambucus racemosa*
black raspberry	RUBULEU	*Rubus leucodermis*
English ivy	HEDHEL	*Hedera helix*
oval-leaved blueberry	VACCOVA	*Vaccinium ovalifolium*
red huckleberry	VACCPAR	*Vaccinium parvifolium*
rusty Pacific menziesii	MENZFER	*Menziesii ferruginea*
salal	GAULSHA	*Gaultheria shallon*
salmonberry	RUBUSPE	*Rubus spectabilis*
Scouler's willow	SALISCO	*Salix Scouleriana*
Herbs:		
burdock	ARCT MIN	*Arctium minus*
buttercup	RANUREP	*Ranunculus repens*
Canadian bunchberry	CORNCAN	*Cornus canadensis*
cat's ear	HYPORAD	*Hypochaeris radicata*
common periwinkle	VINCMIN	*Vinca minor*
deerfern	BLECSPI	*Blechnum spicant*
northern twinflower	LINNBOR	*Linnaea borealis*
orchard grass	DACTGLO	*Dactylus glomerata*
sedge	CAREX	*Carex*
shieldfern	DRYOAUS	*Dryopteris austriaca*
swordfern	POLYMUN	*Polystichum munitum*

Herbs: (continued)		
thistle	CIRSIUM	*Cirsium species*
woodrush	LUZULA	*Luzula species*
Bryophytes:		
alectoria lichen	ALECSAR	*Alectoria sarmentosa*
dicranum moss	DICRFUS	*Dicranum fuscescens*
fungi	FUNGI	*Fungi*
hypnum moss	HYPNCIR	*Hypnum circinatum*
layered moss	HYLOSPL	*Hylocomium splendens*
lichens	LICHEN	*Lichen*
mosses	MUSCI	*Musci*
parmelia lichen	PARMSUL	*Parmelia sulcata*
pyxie cups lichen	CLADPYX	*Cladonia pyxidata*
rhytidiadelphus moss	RHYTLOR	*Rhytidiadelphus loreus*
Forest Pests:		
conifer sawflies	---	*Neodiprion species*
dwarf mistletoe	ARCETSU	*Arceuthobium tsugense*
green-striped forest looper	---	*Melanolophia imitata*
laminated root rot	---	*Phellinum weirii*
western blackheaded budworm	---	*Armillaria ostayae*
western hemlock looper	---	*Acleris gloveriana*
		Lambdina fiscellaris lugubrosa

A.2.2 Estimation of Sulphur Deposition from Litter Fall

A.2.2 Estimation of Sulphur Deposition from Litter Fall

For western hemlock coastal forest:

Table A.2.2 Sulphate Deposition from Coastal Western Hemlock Litter Fall

Western Hemlock:

Foliage: 4% of total biomass[47] (Table 6 pg. 13 of[47])
Biomass: <1100 t/ha[47]
For a low-moderate Site: 500 t/ha total biomass[59,60]
4% = 20 t/ha foliar biomass

Foliar biomass by Age:				Annual $SO_4^=$ (kg/ha) by Age			
Age	Relative	t/ha*	Δ	Lost t/ha	Pristine Environment		SO_2 - Exposed Environment	
					%	kg/ha	%	kg/ha
YR 0	85%	5.0		0	0.1	0	.48	0
			+1.7					
YR 1	100%	6.7		(growth)	0.1	0	.54	0
			-1.7					
YR 2	75%	5.0		1.4	0.1	4.2	.82	34.4
YR 3	40%	2.7		1.9	0.1	5.7	.95	54.1
			-2.0					
YR 4	10%	0.7		1.7	0.1	5.1	1.00	50.9
		20.1		5.0		15.0		139.4

* 20 t/ha consists of total of all ages. Relative distribution is indicated above, so that $\frac{\text{Rel \%}}{300\%} \times \frac{20 \text{ t/ha}}{300} = \text{t/ha}$.

Annual growth is 5.0 t/ha. In year 1 little or no foliage is lost, while some cell elongation and primary thickening takes place, so that at YR 1 foliage has grown to its mature size. The model of foliage loss is reflected in Relative Foliar Biomass by Age: Some loss of foliage will occur in YR 2 (app 1/4). In YR 3 a substantial amount (1/2) of the remaining foliage will be lost. In YR 4 much of the remaining foliage (3/4) will be lost, leaving only

an insignificant amount to be lost in subsequent years. Little, if any, foliage remains on twigs of year 7 and older. In this model a steady state equilibrium between canopy growth and needle loss is presumed. This appears reasonable for healthy mature stands. Information is available in the literature to refine this aspect of the estimates. For better coastal sites these estimated additions to the soil may be double[59,60]. As the tissue sulfur content used in these estimates was obtained from generally highly productive sites it does not seem reasonable to expect that the data will be applicable. In effect the uncertainty in the estimates of the low- to moderate site may be greater than that for the highly productive sites. It is not feasible to make suggestions regarding the error in the lower site estimates, as energy allocation within the plant is not known. The foliar retention model may be compared with the actual foliar retention of western hemlock, coast Douglas-fir, and amabilis fir presented in Table A.2.4 of this Appendix.

Table A.2.3 Sulphate Deposition from Coast Douglas-Fir Litter Fall

Coast Douglas-fir:

Foliage 5% of total biomass
Biomass <1100 t/ha
For low to moderate site: 500 t/ha total biomass
5% = 25 t/ha foliar biomass

Foliar biomass by Age					Annual $SO_4^=$ (kg/ha) by Age			
Age	%	t/ha	Δ	Lost t/ha	Pristine Environment %	kg/ha	SO_2 - Exposed Environment %	kg/ha
YR 0	75	5.3			0.1		0.15	
			+1.7	(growth)		0		
YR 1	100	7.0			0.1		0.4	
			-1.4	1.2		3.5		14
YR 2	80	5.6			0.1		0.4	
			-1.4	1.2		3.5		14
YR 3	60	4.2			0.1		0.4	
			-2.1	1.8		5.4		21.6
YR 4	30	2.1			0.1		0.4	
			-1.4	1.2		3.5		14
YR 5	10	0.7		0.1			0.4	
		24.9	(-6.3)	5.4		15.9		63.6

The annual deposition of sulphate through leaf-fall estimated from approximately 10-20 kg/ha in a pristine environment to in the order of 125-250 kg/ha in a highly affected area such as in the proximity of the Port Alice mill.

For the more sensitive species Coast Douglas-fir such sulphate cycling rates are expected to be somewhat lower.

Table A.2.4 - Percent Foliage Retention of Selected SO_2 Affected(*) and Clean Air Grown Tree Species

		YEAR OF ORIGIN						
SPECIES	SITE	85	84	83	82	81	80	POOLED
wH	(PA8)	100	59.6	28.5	35.7			
	(PA2)*	0	100	22.9				0.7
	(PA6)*	87.7	100	33.6	21.4			
	(PA5A)*	100	39.7	79.0	16.6	11.6	11.9	
	(PA5A)*	58.5	83.2	?	100			
	(PA9)*	100	61.7	6.0				
cD	(PA8)	100	55.1	19.4				1.8
	(PA5B)	0.6	96.8	100	95.7			
	PA5B*	100	26.7					
	PA9	0	25.0	100	63.5	72.2	89.2	
Amf	(PA7)	100	69.7	35.4	41.1			
	(PA8)	100	69.0	65.0	37.1	47.6		

Note: Arrows indicate composite sample of all foliage prior to and including the year at the origin of the arrow. The % foliage retention is indicated below the origin of the arrow.

- The higher weight among the years was selected as the 100% base, excluding composite samples.
- Pooled samples may include foliage from any or/all years. (Unless observations on year by year proportional loss of foliage is available it cannot be determined what the year by year component make-up of the pooled sample is.).
- 1985 represents the current year.

Appendix 3

Plates

PLATE A.3.1

Port Alice pulpmill from monitoring Site 4

PLATE A.3.2

North of Port Alice pulpmill

PLATE A.3.3

Northeast of Port Alice pulpmill, waste dump in foreground

PLATE A.3.4

East to southeast of Port Alice pulpmill, waste dump in foreground

PLATE A.3.5

Port Alice pulpmill and surroundings, from south tip of Neroutsos Inlet

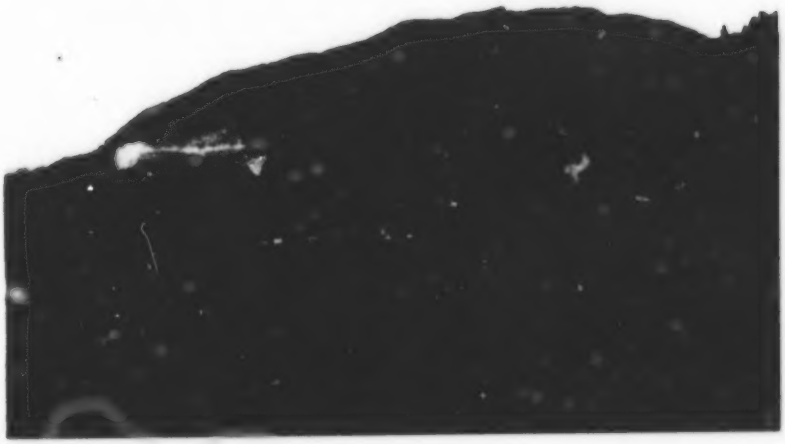
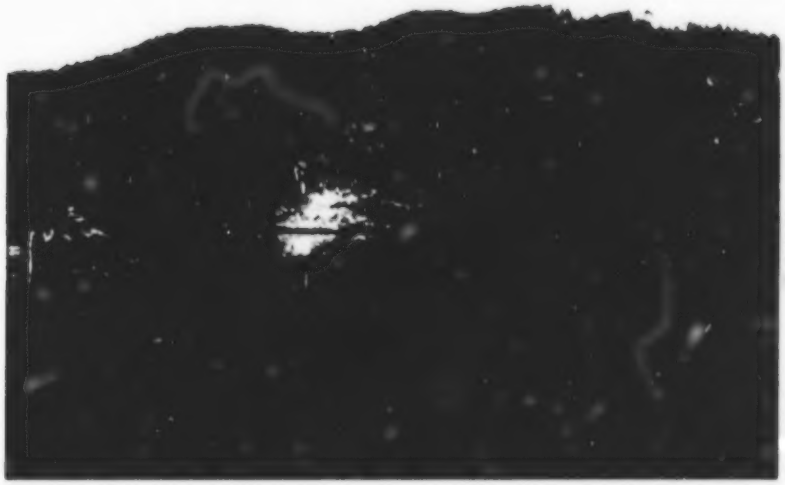


PLATE A.3.6(A)

SO_2 damage near Port Alice pulpmill



(B)

SO_2 damage near Port Alice pulpmill

PLATE A.3.7

Frigon Islets in Neroutsos Inlet, damaged by SO_2

PLATE A.3.8

SO_2 killed trees north of Port Alice pulpmill

PLATE A.3.9

Damaged western bittercherry near Site 1

PLATEA.3.10(A)

Soil profile of Site 1

(B)

Soil profile of Site 1

PLATE A.3.11

Dead, defoliated and chlorotic western hemlock and coast Douglas-fir of Site 1

PLATE A.3.12

Acute injury ("hogstails"), loss of foliage at various years, and chlorosis on western hemlock branches

PLATE A.3.13

Interveinal chlorosis and terminal necrosis of salal at Site 1

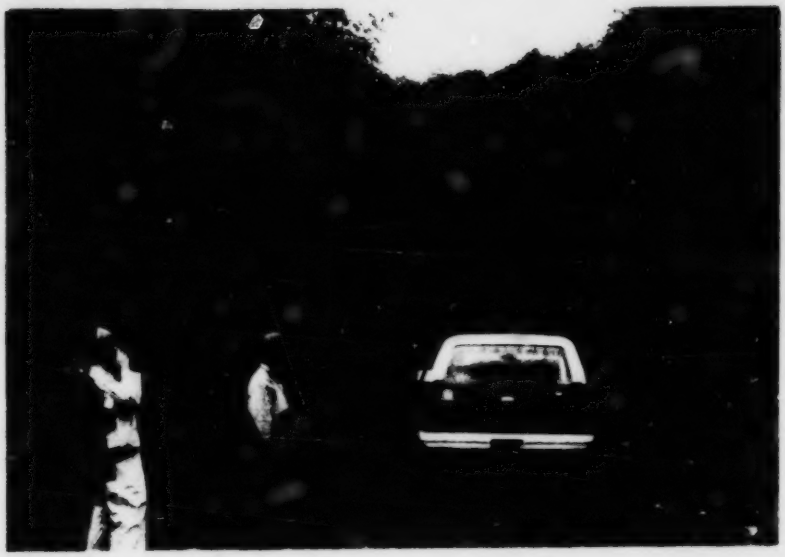


PLATE A.3.14

Ministry of Forests and Canadian Forestry Service pathologists inspect damage at Site 1.

PLATE A.3.15

Severely damaged broadleaf and conifer species of slope north of Port Alice pulpmill

PLATE A.3.16

Sitka spruce branch samples from Site 1

PLATE A.3.17

Acute injury ("hogstails") and severe defoliation of apical branches of western hemlock of Site 3

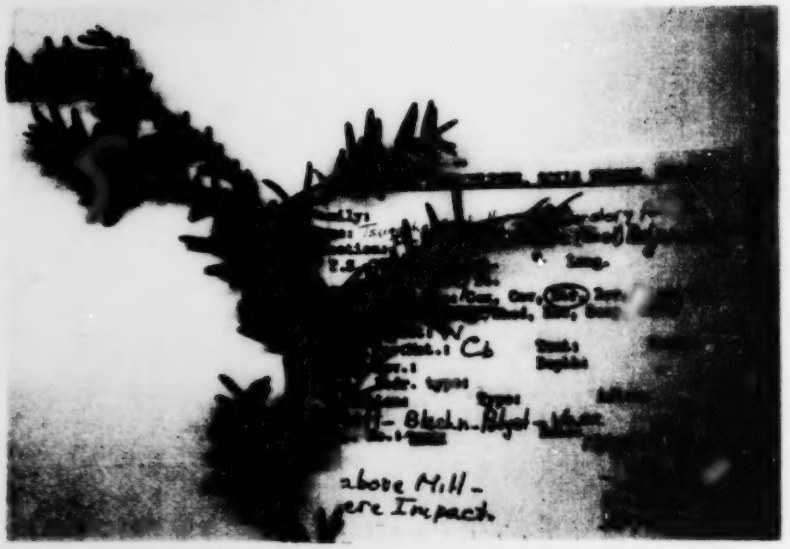


PLATE A.3.18

Moderately defoliated understory western hemlock branch of Site 3

PLATE A.3.19

Defoliation and dwarfshoot formation on western hemlock understory of Site 3

PLATE A.3.20

Twigs from A.3.19 prepared for drying and determinations of foliage:twig ratios for each year, and analysis of foliar tissue for sulphur accumulations

PLATE A.3.21

Soil profile of Site 3 and injured and chlorotic salal

PLATE A.3.22

Interveinal and terminal necrosis, chlorosis and bronzing, acute injury symptoms on deerfern of Site 3

PLATE A.3.23

Chlorotic and dead leaves and curled-up edges on leaves in response to SO_2 stress on elderberry of Site 4

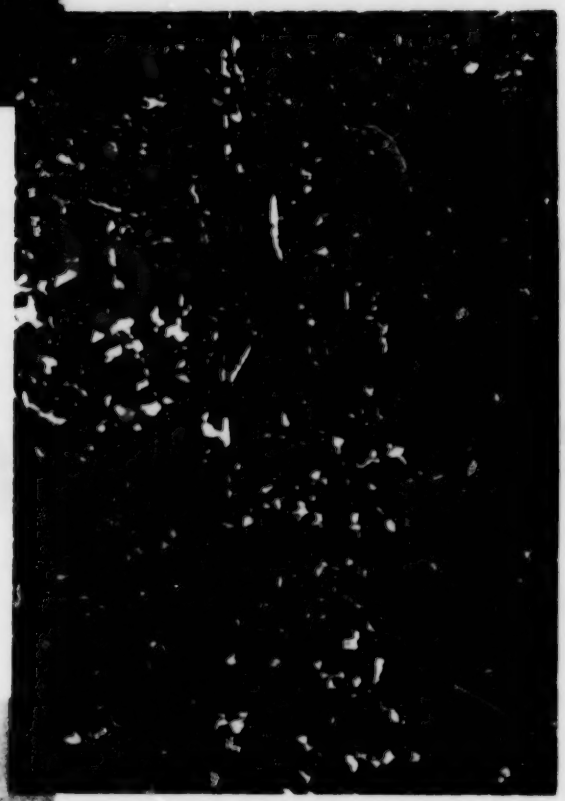


PLATE A.3.24

Western red alder: premature loss of foliage and brown colored bark lacking corticulous lichens and mosses in the "lichen desert" zone of Site 4

PLATE A.3.25

Classical interveinal necrosis and chlorosis on western red alder of Site 4

PLATE A.3.26

Western red alder snags remain standing due to scarcity of decay organisms in "lichen desert" of Site 4

PLATE A.3.27(A)

Classical interveinal necrosis of trailing blackberry leaves on Site 4

(B)

Classical interveinal necrosis of trailing blackberry leaves on Site 4

PLATE A.3.28

Classical interveinal necrosis of maple leaves of Site 4

PLATE A.3.29

Galls of maple leaves probably resulted from injury by mites.

Acute injury: total and interveinal necrosis of swordfern fronds of Site 4; note the "crisp" appearance reflecting rapid desiccation:
a) fronds

PLATE A.3.30

Acute injury: total and interveinal necrosis of swordfern fronds of Site 4; note the "crisp" appearance reflecting rapid desiccation:

b) necrotic pattern detailed

PLATE A.3.31

Interveinal and massive necrosis of salal of Site 4

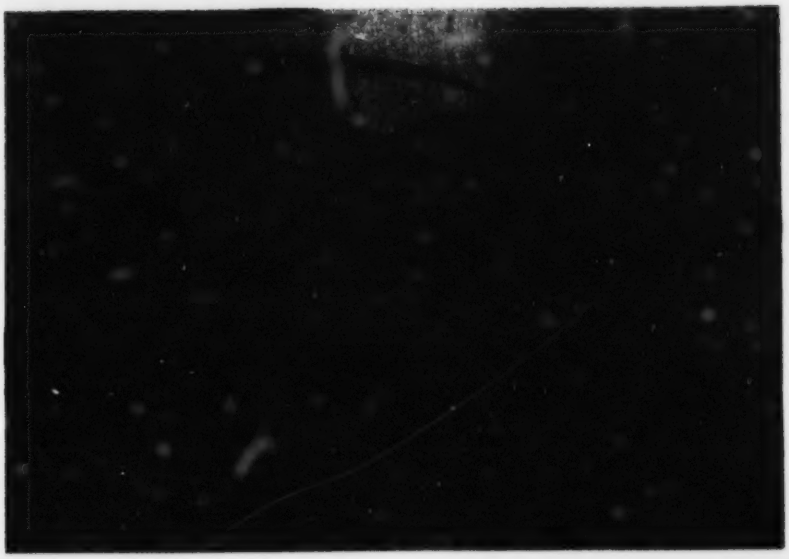
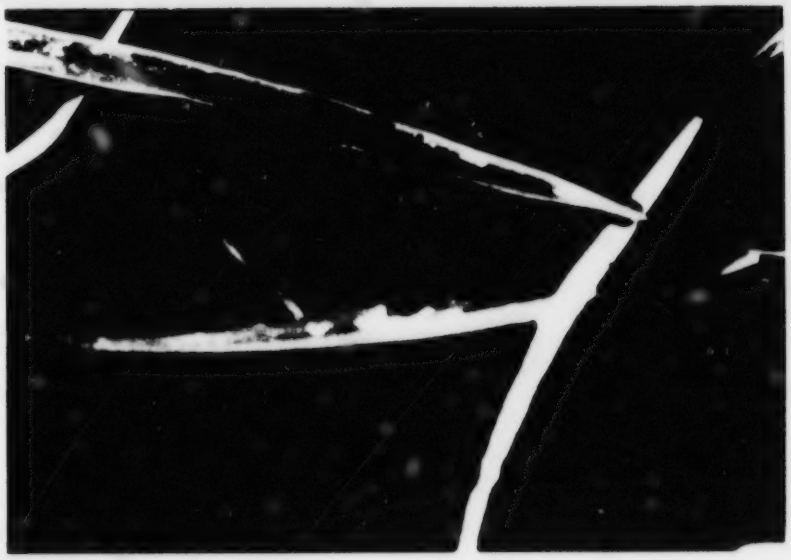


PLATE A.3.32

Orchard grass of Site 4; injury patterns of unknown origin:
a) shoot



Orchard grass of Site 4; injury patterns of unknown origin:

b) leaf detail

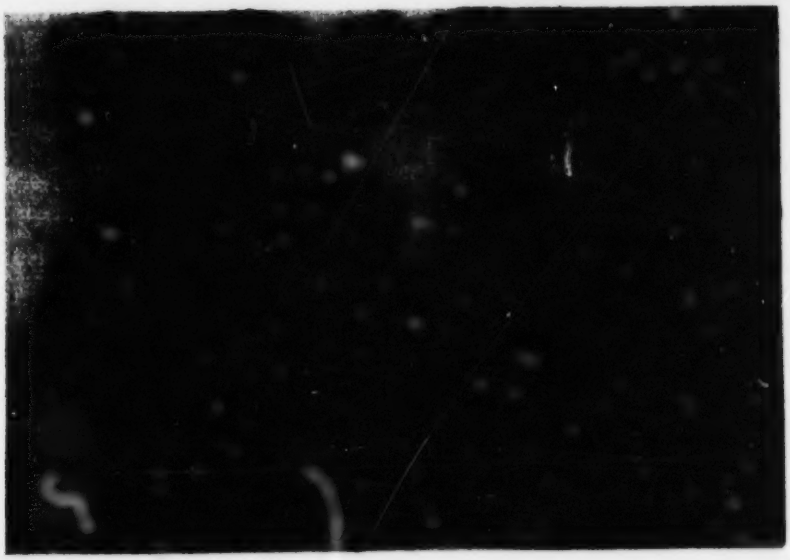


PLATE A.3.33

Buttercup foliage of Site 4 showing light chlorotic patterns and dark "soaked" patterns

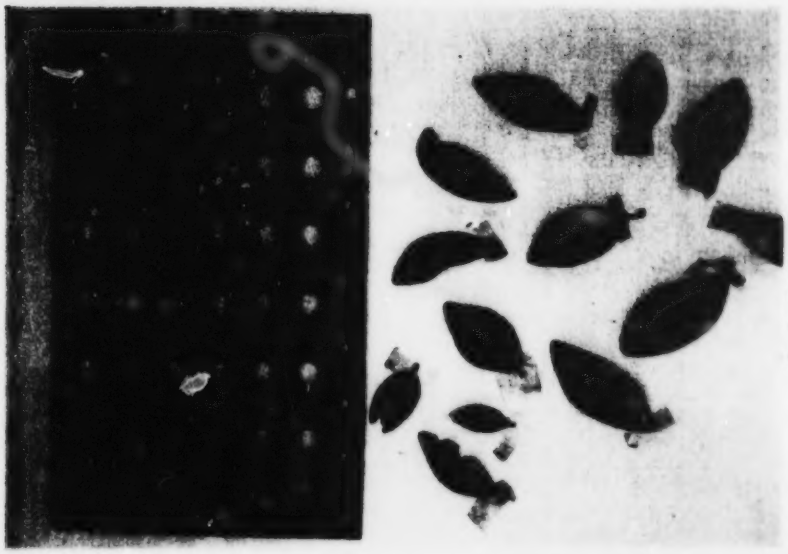


PLATE A.3.34

Foliage of common periwinkle of Site 4 showing slight chlorosis and some "soaked" dark patterns

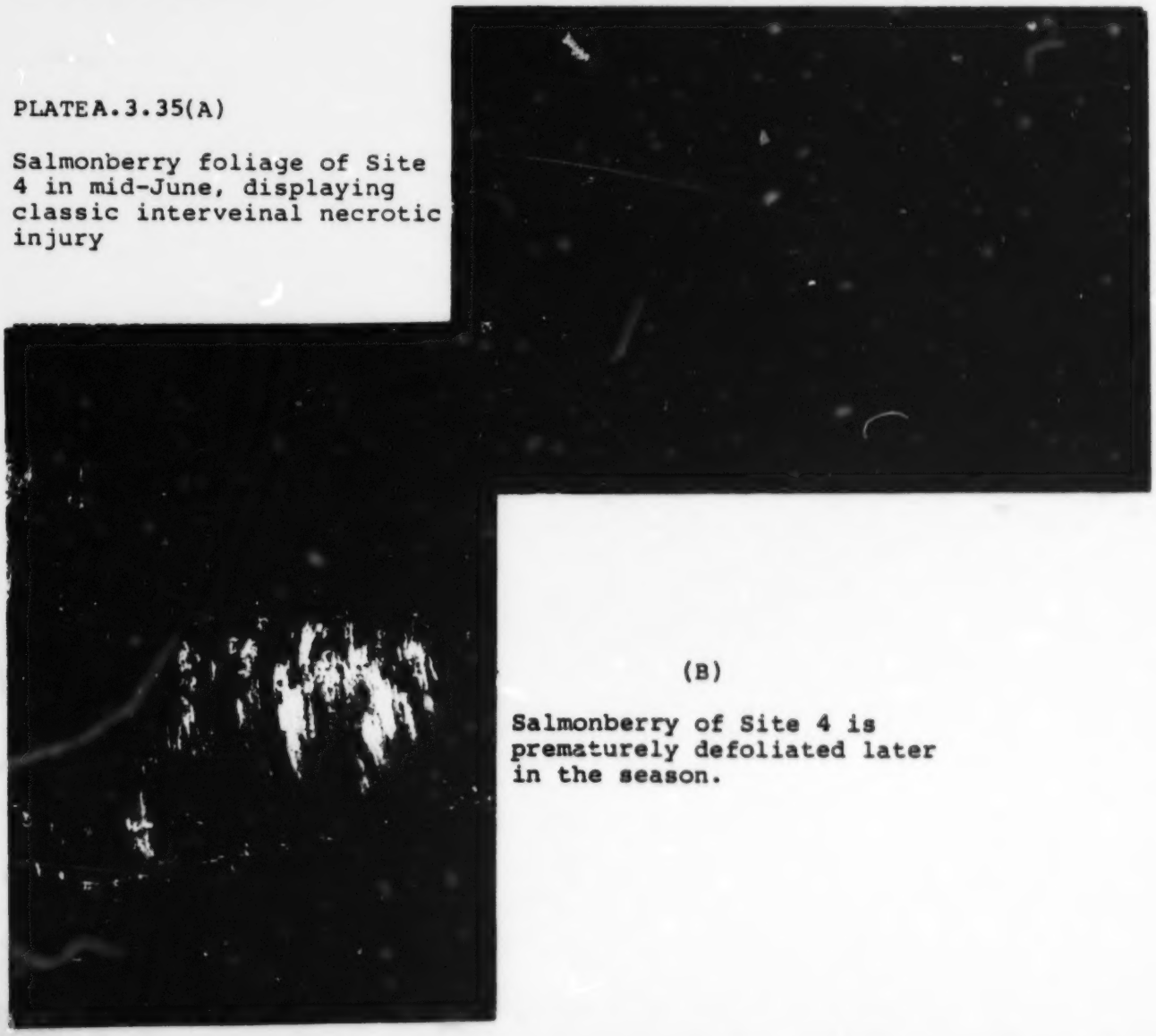
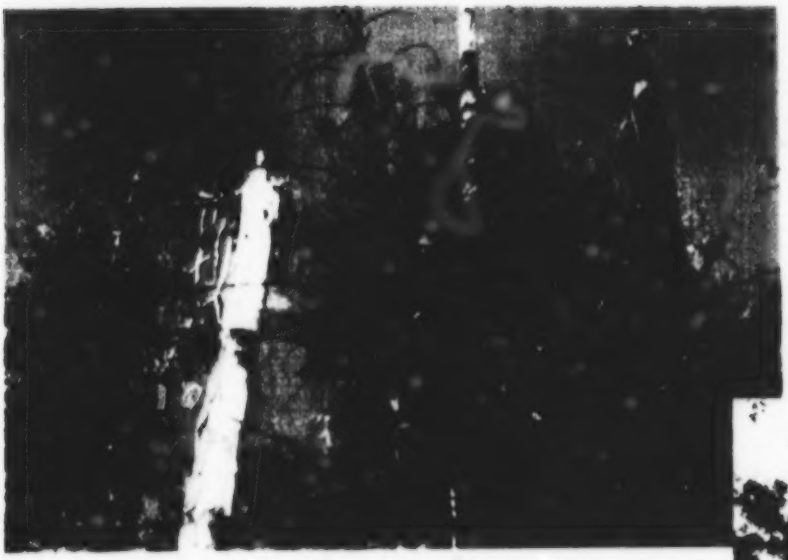


PLATE A.3.35(A)

Salmonberry foliage of Site 4 in mid-June, displaying classic interveinal necrotic injury

(B)

Salmonberry of Site 4 is prematurely defoliated later in the season.



Severe injury and tree-kill on Site 4:
a) western hemlock

PLATE A.3.36

Severe injury and tree-kill on Site 4:

b) red alder

PLATE A.3.37

General vicinity of sampling Site 5A; note dead trees.

Understory foliage of western hemlock of Site 5A is free of visible injury:
a) twig

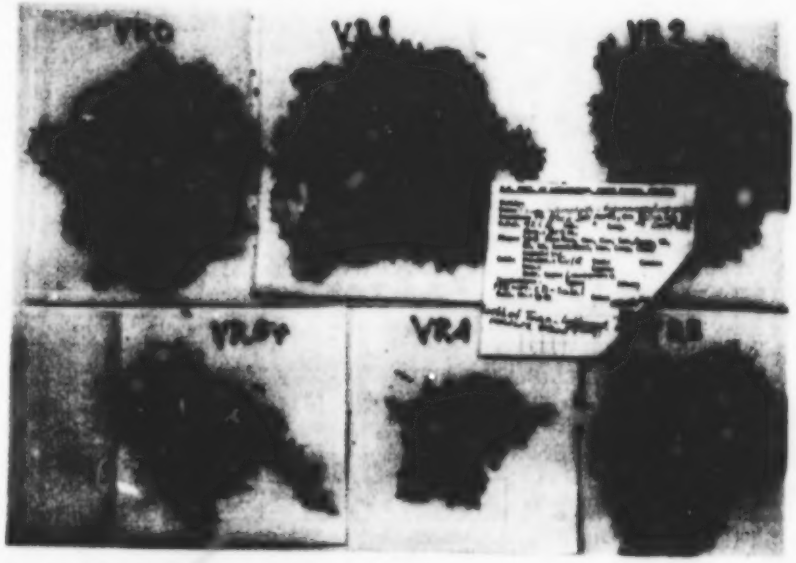


PLATE A.3.38

Understory foliage of western hemlock of Site 5A is free of visible injury:

b) foliage and stems for past years

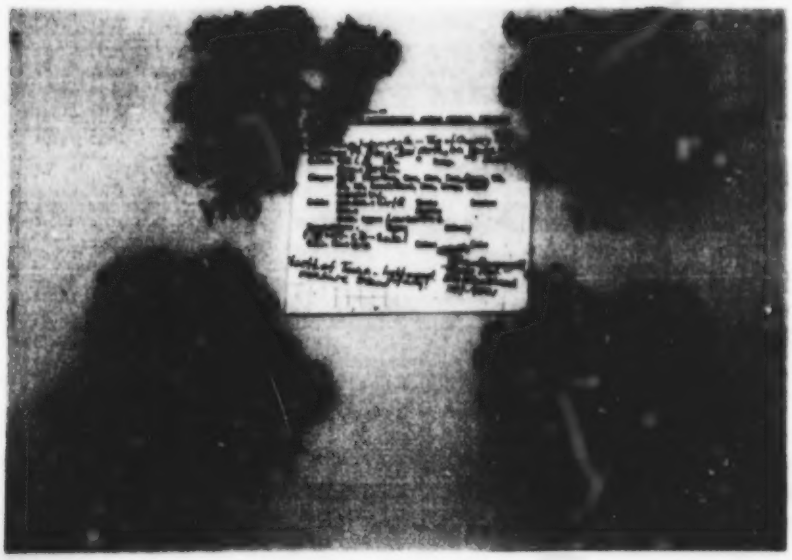


PLATE A.3.39

Apical foliage and stems of western hemlock of Site 5A appears somewhat sparser and may be retained for fewer years.

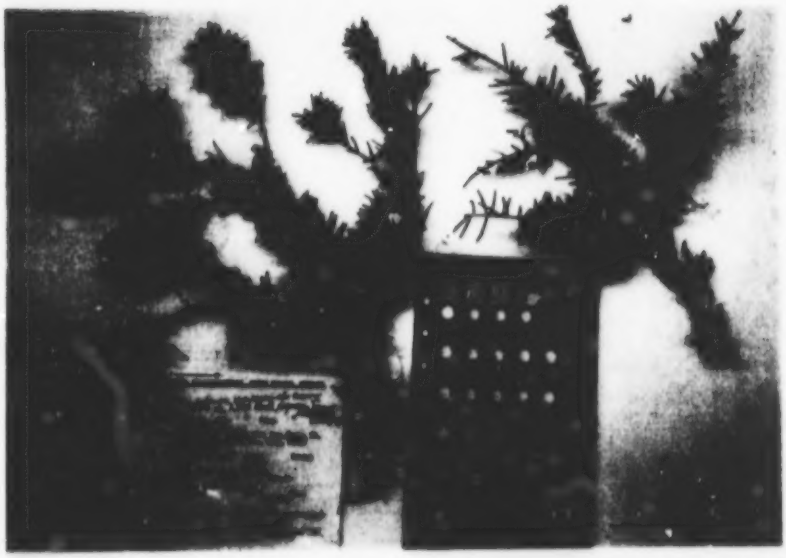


PLATE A.3.40

Defoliation and chlorotic color of coast Douglas-fir regeneration of Site 5B may have been affected by brush control spraying. Total sulphur content of foliage was elevated over background levels.

PLATE A.3.41

In addition to air pollution stress, root rot and brush control spraying and nutrient deficiencies may be involved in chlorosis and dieback of coast Douglas-fir regeneration of Site 5B.

PLATE A.3.42

Some bronzing of western red cedar regeneration of Site 5B may be due to any or a complex of air pollution, nutrient deficiencies and brush control spraying.

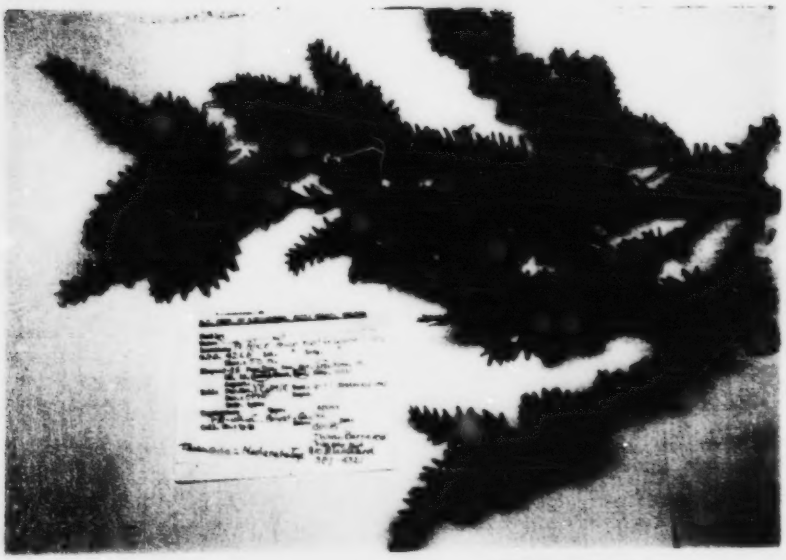


PLATE A.3.43

Understory foliage of western hemlock from Site 6 shows acute injury ("hogstails") and some light defoliation.

PLATE A.3.44

Red alder foliage from Site 6 shows classical symptoms of interveinal chlorosis and necrosis.

PLATE A.3.45

Red elderberry foliage from Site 6 shows severe acute injury symptoms of "soaked" leaf tissue and interveinal chlorosis.

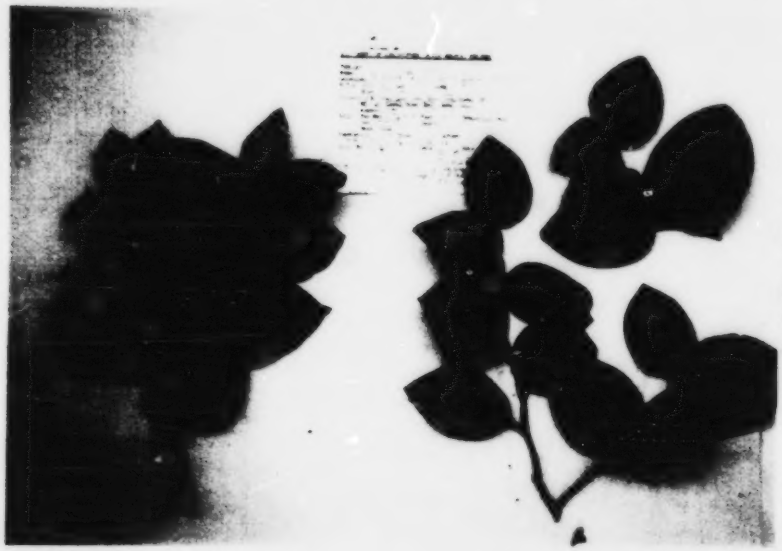


PLATE A.3.46

Salal from Site 6 shows interveinal chlorosis and some marginal necrosis.

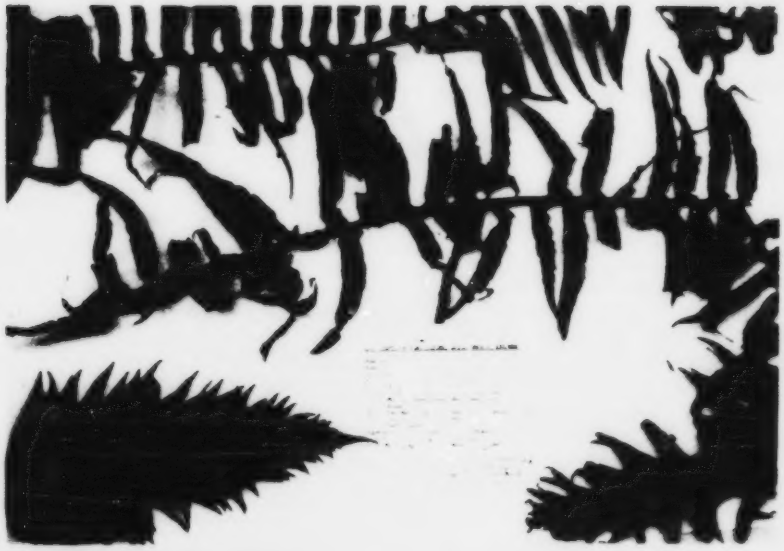


PLATE A.3.47

Swordfern fronds from Site 6 show a range of injury symptoms.

PLATE A.3.48

Red huckleberry foliage senescence may have been affected by SO_2 effects.

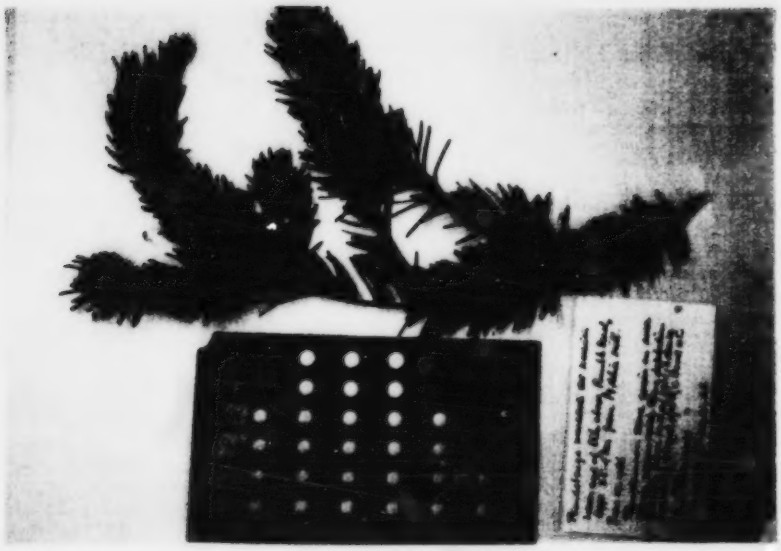


PLATE A.3.49

Coast Douglas-fir branches of near Site 6 display some premature defoliation approximately 3 years ago.

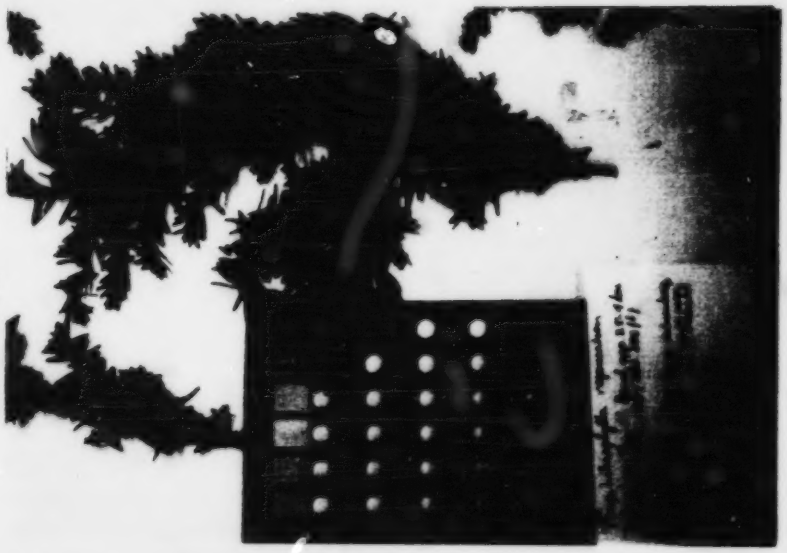


PLATE A.3.50

Some chlorosis of western hemlock regeneration foliage of near Site 6 may have been caused by poor nutrition and air pollution stress.

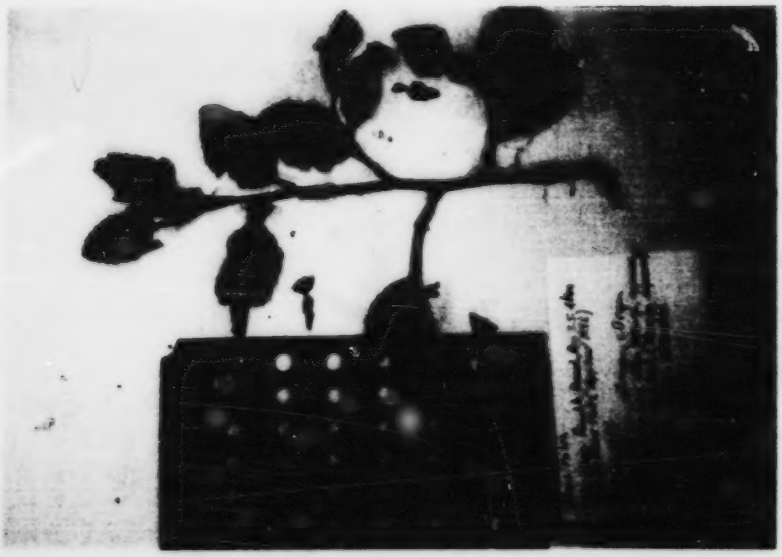


PLATE A.3.51

Classical symptoms of interveinal chlorosis are evident early in the growing season on red alder foliage near Site 6.

PLATE A.3.52

Healthy foliage of western hemlock regeneration at Site 7 near Port Hardy

PLATE A.3.53

Healthy foliage of amabilis fir regeneration at Site 7 near Port Hardy

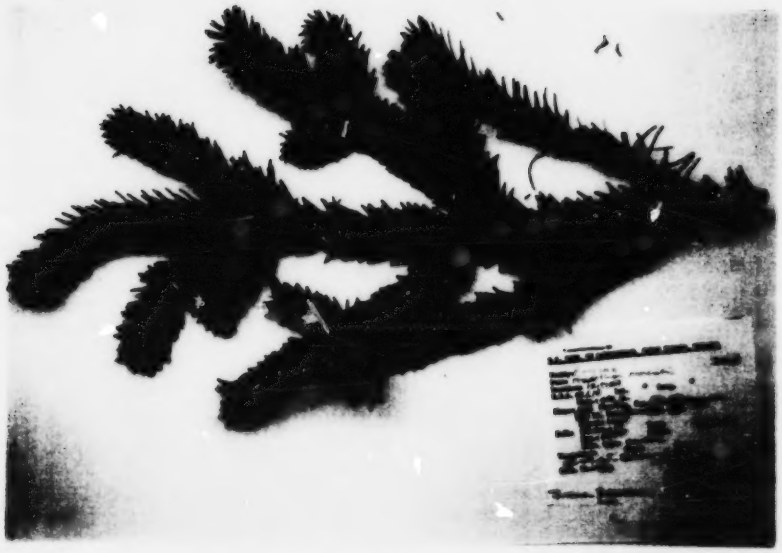
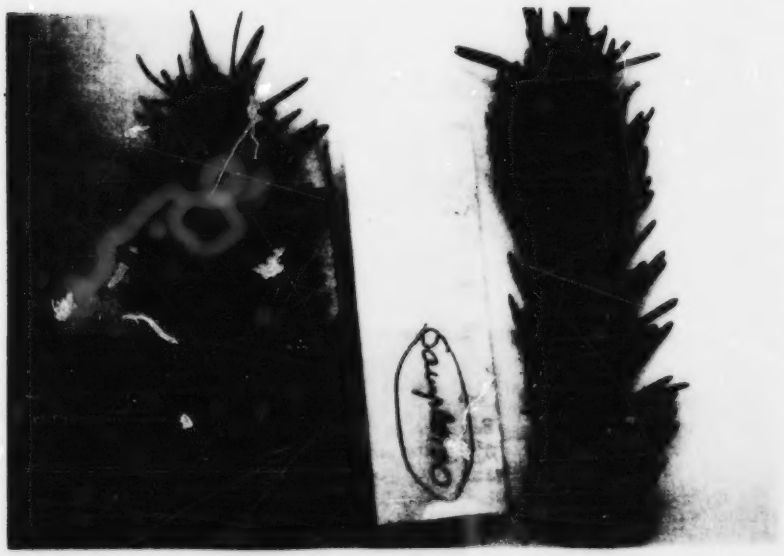


PLATE A.3.54

Healthy coast Douglas-fir regeneration from Site 8 in the Tsitika watershed:
a) twig



Healthy coast Douglas-fir regeneration from Site 8 in the Tsitika watershed:

b) growth of year 2 (1983)

British Columbia
Handle with care
Ministry of Environment

UPDATE

February 12, 1991

As a result of the findings in this report, the Deputy Minister of Environment met with Western Pulp Ltd. Partnership on July 26, 1989. Subsequent to this meeting, the permit for air emissions was amended to reflect a schedule of improvements. The amended permit was issued on November 10, 1989.

The requirements of the amended permit, new Provincial legislation and company initiatives have affected SO_2 emissions as follows:

- A new sulphur burner has been installed in the acid plant.
- The digester blow gas scrubber is to be replaced. Design modifications have postponed the installation date.
- The authorized limit for SO_2 emissions from process stacks has been reduced from 20 kg/ADUt to 13 kg/ADUt.
- A new regulation limits the sulphur content in fuel used in industrial boilers for combustion purposes to 1.1%. A request to permit the use of fuel of 1.5% sulphur is under consideration.
- Western Pulp Ltd. Partnership is required to submit a report outlining further options to improve its emissions to 10 kg/ADUt and 5 kg/ADUt. This information is being reviewed and the Ministry of Environment may consider further reductions in SO_2 emissions as necessary to protect the environment.
- Western Pulp Ltd. Partnership is required to monitor the emissions of SO_2 from the process stacks on a continuous basis and regularly report the results.
- An additional ambient SO_2 monitoring station and a meteorological station have been established. Recent ambient data suggest there has been an improvement over past levels for SO_2 although a detailed statistical evaluation has not been made.